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Edwin Warfield, Jr.,
President.

Dr. Victor L. Loosanoff,
Vice-President.

Dr. J. Nelson Gowanloch,
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## 1947 Addresses

FORMATION OF THE GULF STATES MARINE FISHERIES COMMISSION

James N. McConnell,

Director of the Louisiana Division of Oyster Bottoms

Mr. Chairman, honored guests, and fellow members of the National Shellfisheries Association, it is with a deep sense of appreciation of the opportunity afforded me at this time to give you a little of the background leading to the formation and present status of the Gulf States Marine Fisheries Compact and also, the purpose for which this compact was formed.

At the exploratory Intercoastal Fisheries conference, sponsored by the Council of State Governments and the Committees on Interstate Cooperation, held in Washington, May 16 and 17, 1946, and attended by a group of men from the Gulf Coast, the West Coast and also from the East where the Atlantic States Marine Fisheries Commission has been energetically functioning under its Compact for the past five years, Mr. Hugh Gallagher, Associate Director of the Council of State Governments, Mr. Wayne Heydecker, Secretary and Treasurer of the Atlantic States Marine Fisheries Commission, and Mr. Frederick Zimmerman, Special Advisor to the New York Legislative Committee on Interstate Cooperation explained to us numerous problems of jurisdiction of the marine fisheries and improvement of interstate and Federal-State cooperation with respect thereto.

At this time also at a meeting held at the State Department offices, it was implied to us that very shortly development might occur whereby the State Department would wish to confer with authorized representatives of the fisheries interests of both the Gulf and West Coasts relative to possible international treaties.

Upon return to our homes we of the Gulf area, after conference with others, felt it essential to our fisheries interests, that a Gulf States Marine Fisheries compact be formed.

Accordingly, a preliminary conference was held on October 10, 1946, again under the sponsorship of the Council of State Governments, where representatives of the States of Alabama, Mississippi, Louisiana and Texas met to explore the desirability of such a compact and the procedure for the organization of an interstate fisheries compact and commission comparable with the Atlantic States Marine Fisheries Commission which has been operating with such conspicuous success for the past five years.

These deliberations resulted in the calling December 5 and 7, of another conference with the purpose of enunciating in precise terms the nature, extent and tenets of such a compact and of initiating the necessary actions that would bring into existence a Gulf States Marine Fisheries Commission.

From these deliberations a basic fifteen article tentative compact was formed together with the discussion and further formulation of procedures whereby individual States could extend and adjust the supplementary articles for each of the States.

At this meeting, we were fortunate to have with us, George K. Aiken, Secretary to the Governor of the State of Oregon, and also an official of the then tentative Pacific States organization, who gave us a brief summary of the West Coast Compact, which, at that time, was awaiting ratification, and which has now been ratified and is in operation.

Copies of the compact as formulated at the meeting of December 5 and 6 were sent to the State Department in Washington for their comments and tentative approval. Copies were also sent to the Attorneys General of the five compacting Gulf States of Florida, Alabama, Mississippi, Louisiana and Texas for their recommendations and approval.

A meeting was then called in New Orleans on April 10 and 11, 1947 to complete the compact so that same could be presented to the legislature of the States of Texas, Alabama and Florida, which were either currently in session or about to be called into session.

At this meeting the Attorneys General or their representatives, together with the state officials in charge of Conservation or Marine Fisheries of the compacting States were present as well as members of the United States Fish and Wildlife Service. In addition to this and of most importance was the attendance of representatives of both the House and Senate of the various legislatures of the compacting States. From the State of Texas alone, one member of the Senate and four members of the House of Representatives were very actively present.

The compact in its final form was adopted at this gathering and has been presented to the legislature of the States of Texas, Alabama and Florida, where it has passed the House in all three States and we confidently expect final passage of the enabling act from the legislatures of Texas, Alabama and Florida.

The legislatures of Louisiana and Mississippi do not meet again until 1948 at which time we fully expect these two States to approve the compact.

At this point I wish to sketch to you briefly the aims and purposes of this compact. The compact will promote, develop and conserve the Gulf Coast Fisheries and for this purpose will establish a continuing Interstate Fisheries Commission whose duty it will be to inquire into and report on methods, practices, circumstances, and conditions relative to the prevention of depletion and physical waste of the Gulf Fisheries. It is empowered also to recommend the coordination of State police power and to draft and recommend legislation to further the basic principles of the compact.

From these deliberations a rather lengthy but less legalistic compact was drafted together with some attachments and further stipulation of procedures thereby [illegible] would embrace and adopt the supplementary adherence for each of the States.

At this meeting, we were privileged to have with us, Senator [illegible], Secretary to the Governor of the State of Georgia, and also an official of the State Game and Fresh Water Fish [illegible] organization, who gave us a brief summary of the work carried forward there, at that time, and the existing facilities, all which had not been installed and in operation.

Copies of the compact as formulated at the meeting of December 2 and 3 were sent to all of the [illegible] in Washington for their comments and further suggestions. Copies were also sent to the Attorneys General of the four respective State offices of Florida, Alabama, Mississippi, Louisiana and Texas for their recommendations and approval.

A meeting was then called in New Orleans on April 12 and 13, 1949 to complete the compact so that same could be presented to the Legislatures of the States of Texas, Alabama and Florida, which were either presently in session or would be in session in the quarter.

At this meeting the Attorneys General of these States were present, together with the State officials in charge of conservation and marine fisheries of the respective States, and a representative as well as members of the United States Fish and Wildlife Service. In addition to this, one or more Legislators were present as representatives of both the House and Senate of the various Legislatures of the respective States. [illegible]

The compact in the final form was adopted at this gathering and has been presented to the Legislatures of the States of Texas, Alabama and Florida. Where it has passed the House in all three States and we confidently expect final passage of the compact by and from the Legislatures of Texas, Alabama and Florida.

The Legislatures of Louisiana and Mississippi do not meet again until 1950 at which time we fully expect these two States to approve the compact.

At this point I wish to attempt to give briefly the aims and purposes of this compact. The compact will promote, develop and conserve the Gulf Coast Fisheries and for this purpose will establish a Gulf States Marine Fisheries Commission whose duty it will be to [illegible] into and report on methods, practices, circumstances, and conditions relating to the protection of [illegible] and physical waste of the Gulf fisheries. It is contemplated also to recommend the coordination of State police power and to draft and recommend legislation to protect the basic principles of the compact.

By the compact the United States Fish and Wildlife Service is designated the primary research agency of the Commission and will cooperate with comparable agencies of each of the compacting States.

The compact will further the conservation and development of the fisheries of the Gulf Coast Salt Water Fisheries and should assist materially in bringing to an end numerous interstate controversies.

Another and very important aim of the Commission will be to present in Washington a united front on fishery problems of the Gulf area.

We believe that in unity there is strength and together with the Commissions from the Atlantic States and the West Coast States we can present a solid front in Washington that will be of inestimable value to the entire marine fisheries of these United States.

To give you a concrete example of how the Gulf States Marine Fisheries will work when occasion demands I will read to you a letter sent by me as interim Chairman of the Gulf States Marine Fisheries Commission to interested parties of the five Gulf States pertaining to a matter of the utmost importance to these States.

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The immediate response received and the quick action taken by recipients of this letter in contacting their Senators and Congressmen in Washington acquainting them with what was happening in our section and what it meant to us was indeed gratifying and to me points plainly to great benefits that will accrue to the marine fisheries of the Gulf States when the compact and Commission is legally functioning.

In my humble opinion when all of the Coastal States are so organized to promote, develop and conserve their marine fisheries it will be of the utmost importance to all the fishing interests of the entire nation.

In closing let me thank you for this opportunity of presenting to you some of the background leading up to the formation of, and what may be expected from, the Gulf States Marine Fisheries compact and resultant Commission.

# TEXAS REHABILITATING OYSTER GROUNDS

J. L. Baughman

Chief Marine Biologist, Texas Department of Conservation

Oystering in Texas has been carried on since before the white man first discovered the American continent. Four hundred and twenty-eight years ago Cabeza de Vaca, Texas' first white man, found the Indians of the Texas coast subsisting partially on oysters, and the abundant shell middens from Galveston to Corpus Christi attest the fact that this was a common practice. However, it was not until the latter part of the 19th century that oysters in Texas really came into their own.

To give some ideas of their former abundance I can do no better than to quote from the letter of an old-time oysterman, Mr. Louis Peden, of Galveston, who saw the industry at its height. "In 1890 or '92," he says, "the Givens Oyster Company operated an oyster cannery at Corpus Christi, and was a dominant factor in the area, both in the canning and shucking of oysters, which they sold by the thousands of gallons. The fleet of boats working for this Company hauled from Galveston, Matagorda, Port Lavaca, Rockport, Fulton and Corpus Christi, some of them carrying as much as 500 barrels and I recall that at one time the Givens Company imported several hundred shuckers from Baltimore.

"Most of the oysters came from 'Old Reef' just across the bay. This reef was a wonderful producer, both in quantity and quality.

## Mechanical Exploitation

"It was here I saw my first oyster dredge in operation. In those days it was difficult to operate an oyster dredge from a sail boat and gas engines were unknown. However, someone brought a steam tug into the picture. This tug towed a big barge from which two dredges, each having a capacity of five barrels, were operated, one working while the other was dumped. About 30 Mexicans were employed on the barge, sorting the oysters, and they were kept busy as it only required about 5 minutes to fill one of the dredges. In only a little over a year 'Old Reef' was gone.

"In the Port Lavaca area a man could easily tong from 7 to 30 barrels a day, and, in one day, a crew of 3 men on the schooner LEONORA, tonged 135 barrels. Oysters were so plentiful that dealers placed a limit on the barrels a boat could bring in for supply far outran the demand, and the difficulty was not to get the oysters, but to find some place where you could sell them. I have seen oysters sold for 15 cents a hundred, shucked.

"Oystermen were everywhere, and one day, on 'Half Moon Reef' (off Port Lavaca) I counted 287 boats fishing that reef."

This was the heyday of Texas oystering, but even before that time some of the more foresighted oystermen had felt that this was the beginning of the end. The advent of power boats and dredges, the ruthless and uncontrolled stripping of the reefs, all combined, were too much for the oysters and, although production in 1904 reached a peak of 199,000 barrels, by 1908 the production had dropped to 102,000 barrels, and from that time on the production and quality of Texas oysters began a steady decline, reaching an all time low in 1943-44 of 36,981 barrels.

Other factors contributed to this also. In 1913 and 1914 much of the Texas coast was swept by freshets from both the Colorado and Brazos, killing off the oysters in Matagorda Bay.

A third cause for the decline, particularly in Galveston Bay, was the use of oyster shell to produce lime, cement, chicken feed, and magnesium. The result has been that, between the shell dredges and increasing industrial pollution, there is hardly a producing bed in what was once one of the most fecund producing grounds in the State.

Here then are the causes of our decline, in the order of their importance: (1) Destruction of grounds by sedimentation and floods, affecting the Matagorda area. (2) Lack of management and uncontrolled exploitation, affecting the entire coast. (3) Destruction of live reefs by shell dredges, affecting Galveston, Corpus Christi, Aransas, Lavaca and Carancahua Bays. (4) Industrial pollution, affecting Galveston, Nueces and Corpus Christi Bays.

A fifth cause, mortality from oyster pests, is negligible, as they are few on the Texas coast, with the exception of Nematopsis. Very heavy infestations of this parasite of the crab and the oyster are present on portions of our coast, particularly Copano Bay.

Our main problems, then, are rehabilitation of our reefs, and perpetuation of our oyster crop by wise regulation and management.

## Present Program

It has not seemed desirable to attempt any extensive planting for several reasons. In the first place it is expensive, costing, if we plant seed oysters, at least $150 per acre, and with huge areas of denuded reef and bottom needing reseeding this would run into many millions of dollars. Moreover, this would amount to an outright subsidy of the oystermen, who can take oysters from these grounds just as they can from natural reefs, without making any return to the State.

A second reason was the impossibility of patrolling such planting thoroughly, except in limited areas, and the consequent lack of assurance that the seed would be allowed to attain maturity.

Consequently it was thought best to undertake the study of this problem by making a number of experimental plantings with a view to discovering the best type of bottom in the area for such replanting, always bearing in mind that because of our Texas law it was not possible for the oyster farmer to lease the most suitable area, i. e., a natural reef, even though denuded.

Secondly we wished to discover the most desirable density of planting for the area and, thirdly, what type of seed can be used most advantageously.

This work at present is being carried on in two areas, Aransas Bay at Rockport, and South Bay at Port Isabel, but the Port Isabel work is of little interest except to determine the rate of growth of oysters in the very high salinity of that portion of our coast. The use of Aransas Bay close to Rockport was the result of two very practical considerations. The first was that we can see all our experimental plantings from the laboratory windows, thus reducing the danger of unauthorized oystering. The second was the closeness of the seed beds in Copano Bay. These Copano oysters are of poor quality, thin, dwarfed, and the meats are frequently discolored and almost always heavily infested with Nematopsis, the mantles, gills, blood vessels and even the water tubes of the gills being full of cysts and single spores.

In spite of such infestation oysters transplanted from Copano to Aransas Bay showed a remarkable recovery. Several weeks after planting the meats were firmer, whiter and contained more glycogen, while there was a noticeable increase in the size of the shells. So far (five months after planting) they are doing well, and barring storms or other acts of God, there seems little reason to apprehend any more than normal loss.

## Cooperative Reseeding

One thing that we are trying, however, is a considerable departure from accepted methods of rehabilitation. This is the salvaging of seed oysters from the shucking houses.

In Texas it is the custom for oystermen delivering oysters to the shucking houses to be paid by the number of gallons shucked from the load, rather than by the number of bushels entering the plant. The result is that the shell piles around the shucking plants present a shocking and depressing sight, for nearly every one of the shells opened by the shuckers has from 2 to 10 seed oysters about one inch long attached to it. At a conservative estimate, the houses destroy, at this rate, five young oysters for every one of marketable size that they open, for the custom has been for years to allow the coastal countries to utilize this shell for road building, and at times the stench of rotting oysters along a new road was almost insupportable.

At the beginning of this year, in the Rockport area, the State laboratory instituted a new method of handling this shell. Almost every barrel of it was returned to the water within 48 hours and planted on suitable ground, with the result that most of this seed was saved, and at the present writing is growing and doing well, although there was some mortality in sizes less than 1 inch. Eleven thousand barrels of 8100 cubic inches capacity of this seed were planted at a cost of 15¢ per barrel.

It is our hope that by experimental plantings such as these we can work out the problems that are too expensive for the ordinary oystermen, and induce them to begin sowing in order that they may reap, for if they do not the Texas oyster industry is doomed.

At the same time we are not neglecting other things. An effort is being made to revise our leasing laws so that we can lease denuded reefs for planting, and in the Galveston Bay area, much work is being done on pollution control. Moreover, we now have under construction a modern marine laboratory at Rockport.

To quote from Dr. Galtsoff, who was a recent visitor, "The construction of a new State fisheries laboratory at Rockport will give the State biologists an opportunity for a more critical study of various fishery problems of the State. Undoubtedly, the new center of research will have great educational influence on fishermen. Conservation of natural fishery resources is impossible without the understanding of its aim by the fishermen and without their active cooperation.

"It is hoped that a good plan started by the State in showing the oystermen how to grow more and better oysters will bring results and that local oyster dealers will gradually come to realize that their business is doomed unless effective steps are made to stop wasteful practices. By leasing from the State oyster bottoms suitable for cultivation and by returning to them the seed which is at present destroyed, substantial oyster resources can be built and the oyster industry of the State may be placed on a sound basis.

"The State Game, Fish and Oyster Commission can be of great help in the rehabilitation of oyster resources by providing, through its technical staff and its laboratory, information and advice, and by establishing demonstration oyster farms. This type of activity seems to be very promising. It is believed that it may substantially contribute to the rehabilitation and conservation of oyster resources of the State".

# PRESENT STATUS OF THE CHESAPEAKE BAY OYSTER BARS IN MARYLAND

Ralph C. Hammer

Shellfish Culturist, Maryland Department of Tidewater Fisheries

This report will endeavor to briefly summarize the history, the present condition, and the need for restoration of the Chesapeake Bay Oyster Bars. At this time, however, it is with considerable pleasure we acknowledge the very valuable and essential technical assistance supplied by the Maryland Department of Research and Education and the U. S. Fish and Wildlife Service. These cooperating agencies have been most helpful through their coordinated studies in supplying the information necessary for the management of the oyster resources of Maryland. Representatives of these agencies, Mr. G. Francis Beaven and Mr. James B. Engle, will report on a portion of their scientific studies following this presentation.

Maryland formerly enjoyed what seemed to be an unlimited supply of oysters from her comparatively vast acreage of oyster bars. Like many of our natural resources, the 272,145 acres of charted natural oyster bars in Maryland have declined in production from an average annual yield of 12,250,000 bushels, during the period from 1870 to 1890, to the present annual production of less than $2\frac{1}{2}$ million bushels, or approximately one fifth of the former high level of production. There is little necessity to point out to this group that the decline in Maryland's oyster resources is almost entirely a result of the same factor which has made us all conservation conscious; that is, man's rate of harvest has been in excess of natural reproduction. Natural oyster enemies are virtually nonexistent in Maryland, with the exception of occasional screw borer depredations in limited areas of higher salinities and occasional mortalities as a result of infrequent periods of low salinities in the upper Bay areas. The destructiveness of the lowered salinities was discussed in detail at the 1946 Shellfisheries' meeting (Engle). In the absence of major natural catastrophies, the continued downward trend in oyster production must be attributed to overfishing without regard for rehabilitation. As a result, many bars are today completely devoid of oysters and cultch, and it is these bars in the Chesapeake Bay proper, that now need a well planned program of restoration.

The oyster bars of Maryland can be roughly classified into two major groups, tributary and Bay bars. Production today is derived almost entirely from the tributary waters as a result of the more consistent spat sets on these shallow water bars and to the relatively inefficient use of tongs in harvesting. The tributary bars have continued to be largely self-sustaining and will continue to yield at a moderate rate, and following years of exceptionally favorable spat sets, may produce large quantities of oysters. State shell planting has been largely successful on most of these tributary bars and under existing conditions are to be continued.

The major problem of State Management lies in the wise utilization of the dredging bars in the Chesapeake Bay. It is these bars or some 78,342 acres that are virtually barren. The Bay bars were originally most productive and gave rise to the famous Chesapeake Bay oyster. During the aforementioned peak years, 1870 to 1890, the yield of oysters from the Bay bars averaged 50 bushels per acre annually. Upward of 1000 dredge boats were engaged in this free fishery but as one bar after another became depleted, the number of dredgers decreased until last season, 1946-47, there remained but 48 licensed Bay dredgers. The catch in turn dropped from the cited 50 bushels per acre to approximately one bushel per acre last season or a total yield of less than 100,000 bushels.

Of the total charted bars in the Bay, 6,714 acres are in that area commonly referred to as the Head of the Bay. This Upper Bay area is subjected to periodic freshets, as evidenced by the vast accumulation of shells and as revealed in recent scientific studies. In view of this hazard of freshets and the very infrequent spat sets, no consistent management program has been undertaken. In recent years, the policy has been to utilize this area as a source of seed and at times for the harvesting of market oysters. Although this area is commonly called a seed area, present studies indicate that the production of seed is infrequent; therefore, it appears to be wise to utilize promptly such seed or market oysters as may develop. Of the remaining oyster bars in the Bay, it is estimated that a minimum of 60,000 acres are ideally suited for oyster growth and are capable of producing quality oysters in quantities comparable to the best leased bars in other States. Due to the depth of water and exposure, these bars are dredged by boats under sail. Dredging by power is prohibited by law. In spite of the inefficiency of sail boats, the use of the dredge in removing both oysters and cultch, coupled with infrequent sets, is responsible for the present condition of the bars. State Management although effective in most tonging areas has not brought about a recovery of these dredging areas. This failure cannot be attributed to the fault of the program, since the practice has been to follow the best methods employed by the private planter on personally controlled leased bottoms. In brief, State Management has been to select favorable growing bars, plant seed oysters, close the bars to public fishing until a majority of the oysters have reached a marketable size, and then open the bars to public dredging. A tax of 20¢ per bushel, harvested, was collected in an effort to recover the cost of planting. Although this tax of 20¢ has only in a few cases been sufficient to cover costs, this large scale experimental planting program has been successful and has produced oysters at a nominal cost. During the past seven years, 865 acres or approximately 1% of the Bay bars were planted with seed or shells, at an expenditure of $96,366. These plantings produced over 210,712 bushels of oysters or an average expenditure of 46¢ per bushel harvested. Although 46¢ may be considered a fair price to produce a bushel of oysters, experience reveals that a considerable reduction in costs may be possible. For example, Poplar Island Bar was planted in 1944 and 1945 with seed costing $4,797. Last winter, 1946-47, 35,000 bushels of quality oysters were harvested at a production cost of 14¢ per bushel. For those interested in oyster planting, 22,560 bushels of seed were planted to produce the 35,000 bushels of oysters.

The State's efforts to grow oysters at a nominal cost, upon analysis, appear to be successful and indicate the need for an expansion of the present methods. However, there are several serious difficulties which have become apparent if the State is to embark on a full scale program to bring all of the Bay bars back into maximum production. The foremost problems facing the State, if such an ambitious program is to be undertaken, may be cited as follows: (1) To return the Bay to productivity will require a considerable period of time. The present supply of shells is inadequate to launch into a program of rapid restoration without neglecting the present policy of planting shells in tributary waters. Undoubtedly, the industry would object seriously to the use of more than a small portion of the shells now available from oysters taken in the tributaries to restore the Bay bars. (2) A very large investment of State funds would be necessary. With the present trend to curtail state expenditures, it is doubtful whether a minimum of seven million dollars would be appropriated over a period of 25 years, with no assurance of this resource becoming self-supporting for many years, if then. In addition, there is little assurance that the original investment, a direct subsidy, would ever be recovered by the State. (3) Such a program of State Oyster Farming should be made self-supporting, that is, a tax of at least 40¢ per bushel harvested must be collected to defray planting costs. If such a tax were authorized, its collection would be difficult, especially during periods of low prices. The dredger, at present, resists the payment of the present 20¢ bushel tax in spite of favorable markets. Therefore, there is some doubt whether an increased tax would be authorized. (4) The tongers fear over-production and glutted markets if the Bay were restored to full productivity. They also oppose any large scale leasing plan because of the fear that such a plan would gain sufficient momentum to eventually include the leasing of the tributary bars.

In conclusion, there is general agreement throughout the State that something must be done. The likelihood that nature alone can re-populate the Bay is only remotely possible in the far distant future, if ever, with the continuance of a free fishery system. State Management can and has grown oysters at a reasonable cost. The available funds, however, limit this operation to a minimum, as evidenced by the planting of one per cent of the available acreage in seven years. Studies of the problem indicate thus far but one solution; that is, some form of private enterprise or leasing. Past efforts to permit leasing have met with strong opposition from the Tidewater communities, with the result that legislative defeat of leasing proposals has continued as recently as March 1947. The practical and biological aspects of oyster culture are advanced sufficiently to initiate and maintain production but, in spite of these advances, the problem of restoration of this potentially valuable resource still remains in doubt.

# OBSERVATIONS ON FOULING OF SHELLS IN THE CHESAPEAKE AREA

G. Francis Beaven

Biologist, Maryland Department of Research and Education

During recent years, extensive data have been accumulated at Solomons concerning the attachment of fouling organisms to oyster shells in local waters. Three phases of the problem have been studied: (1) the kind, and range within the area, of the major organisms which cause fouling of oyster cultch, (2) the rapidity and extent with which specific organisms occupy the shell surface, and (3) the season of attachment and effect upon the organisms of climatological variations as reflected in water temperatures and salinities. Observations also have been made which indicate the comparative efficiency as cultch of planted oyster shell during the first and second spawning seasons. Parallel data on the period and intensity of oyster setting indicate how improved timing of shell plantings might increase the effective catch of spat.

Data on fouling have been gathered during visits to shell plantings at various seasons of the year, in connection with periodic studies of the composition of natural bars, and from clean shells exposed in numbered wire bags for various time intervals throughout the year. Special collecting trips were made during the summers of 1943 and 1944 to study the distribution of Bryozoa throughout the Chesapeake and in Chincoteague Bay.

Fouling in the Chesapeake area appears to be caused principally by Bryozoa, barnacles, mussels, Molgula, sponges, tube building worms, Folliculinids, Crepidula, Hydroids, Algae, and various microorganisms forming organic films. In a number of instances one or more of these agencies have been found to completely cover all exposed surfaces of planted shells in a comparatively short period leaving no suitable areas for spat attachment. Such fouling may thus at times be a major factor in determining the success of spat fall. Competing organisms also may smother newly attached spat in some instances or, on the credit side, their growth across the shell surface may result in loose attachment of the growing young oysters so that they easily scale off from the cultch and become single.

One of the most serious fouling agencies from the standpoint of oyster setting is the group of small colonial, single celled animals known as Bryozoa. Twenty-eight species have been found in the Bay but only two of these are found to heavily encrust oysters and oyster shells. They are Acanthodesia tenuis and Membranipora crustulenta. Both form a meshlike layer of calcified walled cells across the shell surface, the former often producing layer upon layer and sometimes making folds or frills several inches in thickness. These two species occur throughout the oyster producing waters of the region but are especially abundant at salinities of approximately 10-18 $^{0}/_{00}$. Setting generally occurs when water temperatures are 20° C or higher and is most intense during the latter part of the summer.

In reproduction Bryozoa produce ciliated larvae which swim about for a short time, then attach to shells or other objects and within a few hours metamorphose into an "ancestrula" or primary individual of the colony. Occasionally a twin ancestrula is produced as is true of Acanthodesia. Buds of the first generation of new cells or daughter zooecia usually appear within a few hours and subsequent rows of new cells around the spreading colony may be produced at the rate of two a day. Although the length of a single cell is only about one half millimeter, the colony, generally fan-shaped at first and then circular, expands all around the border at the rate of one millimeter a day so that it is possible for a single colony to reach two inches across in 25 days. This rate of growth frequently occurs during the summer under such environmental conditions as prevail at Solomons. On clean shells exposed for one week in this region, counts as high as 2000 colonies on the inner surface of 10 shells at times have been made. It is thus not unusual to find the surface of clean shells completely encrusted by Bryozoa within a three week's period under favorable conditions.

Fortunately Bryozoa do not thrive as vigorously in the seed areas and other portions of the State as they do in the mid-bay section. Also, intense Bryozoa setting occurs in late summer so that during the first part of the oyster spawning season ample Bryozoa-free surface on planted shells is left for the attachment of spat. Heavy subsequent growths of Bryozoa do not appear harmful to the young oysters but serve to prevent their firm adherence to the cultch and to one another so that clustered oysters may be separated easily. In most places, however, Bryozoa growth does greatly decrease late season oyster setting on spring planted shells in the Solomons area. Delaying of shell planting until an oyster set seems imminent appears to be the surest way of minimizing interference from this organism.

Barnacle setting also has been found to be much heavier on clean newly planted shells than on oysters and old cultch. Although barnacles are found throughout the area they are more abundant at salinities under 20 $^{o}/oo$. In waters of higher salinity many barnacles are killed by drills and again competition with sponges and other organisms is more severe than at the lower salinities. Two periods of intense setting are found in the Solomons area, one during April or May and the other during November or December. Peak setting in both cases occurs when water temperatures are about 15° C. High counts of approximately 1500 barnacles per 10 inner surfaces of shells during a week's exposure were made in both May and November of 1946. After a few week's growth, barnacle sets of this intensity may completely encrust all exposed shell surfaces. While spat are occasionally found attached to barnacles, the efficiency of the barnacle coated shells as cultch is greatly decreased. Few or no barnacles have been found to attach on shells exposed during late June and July, the usual period of most active oyster setting in Maryland, and again during February and March. Unfortunately, the spring period of heavy barnacle setting frequently coincides with the time when State shell plantings are being made. Loss of cultch

efficiency from barnacle fouling could be almost entirely eliminated by delaying shell planting until after June 1st.

Mussels are most abundant on the bars of the upper portion of the Bay and its tributaries where salinities are low. Setting of this organism appears to be of minor importance as a hindrance to oyster setting on planted shells but may so encrust growing oysters and old cultch that all surfaces are completely covered. In one recorded instance a typical bushel of dredged oysters from a State planting which was ready for harvesting was found, when all mussels had been shaved off, to consist of $\frac{1}{2}$ bushel of oysters and $\frac{1}{2}$ bushel of mussels, thus greatly lowering the market value of oysters produced on this bar. Subsequent working and culling decreased the proportion of mussels, however, as harvesting of the bar proceeded. Mytilopsis, a bivalve very similar to mussels, is commonly found on oysters and cultch at the lowermost salinities under which oysters occur.

Molgula or sea squirts become very abundant on many bars during the fall and winter months. They interfere with oyster harvesting but do not appear to interfere seriously with oyster setting. Heavy aggregations of them sometimes die en masse in late winter or early spring to form a smothering deposit of decaying material which has been believed to be the causative agent for occasional oyster mortalities occurring simultaneously.

Various encrusting sponges are very abundant on the deeper rocks of Tangier Sound during the fall where salinities are generally above 20 ‰. They make harvesting difficult and apparently may smother some spat or small oysters. Boring sponge is commoner also at higher salinities and often riddles both shells and oysters. Sponges in general seem to cause little interference to oyster setting on planted shells during the first season, but may be responsible for a considerable decrease in cultch efficiency during the following years. These and the boring clam commonly found in shell in the Tangier area convert the cultch rather rapidly to crumbly shell fragments or "cinder".

Several species of tube building annelid worms are commonly found which may cover considerable surface on clean shells rather rapidly. The Serpulids which build contorted calcareous tubes are found where salinities range above 15 ‰ and the Sabellids or membranous tube builders are of more general distribution. Fouling by worm tubes generally is not severe, but occasional local abundance of Sabellaria has completely encrusted shells and oysters with deposits an inch or more in thickness, preventing attachment or killing all spat and smothering many oysters. Such occurrences are rare and have only been observed under conditions where the bottom contains fine sand or silt which may be roiled by wave action keeping the water heavily laden with the silt used by the worms in constructing their tubes.

Crepidula and Anomia occur in waters where the salinity ranges above 15 ‰ but have not been numerous enough to be considered serious fouling agents. These and oyster drills fluctuate widely in abundance

with seasons of varying salinities sometimes almost disappearing in Maryland waters of the Chesapeake system after seasons of heavy fresh water run-off and at other times building up to high levels after a series of dry years.

Folliculinids are often abundant on clean shells and are found at all seasons but do not appear to have adversely affected oyster setting or survival. Hydroids are sometimes quite abundant locally in winter but mostly disappear from the shells during the warmer seasons and seem not to affect oyster life. Some of the larger algae are of common occurrence in the Chesapeake but are usually not abundant and have not been considered detrimental to oyster life. However, in the shallow waters of Chincoteague Bay at salinities ranging around 30 $^{0}/oo$ dense mats of algae sometimes accumulate over oyster beds and, especially when the algae are dying, cause serious interference with water circulation so that the oysters become very poor or may die in large numbers locally.

An organic film containing many diatoms, algae, bacteria and other small organisms together with accumulated silt usually develops over most shell surfaces which have remained in the water for some weeks. This decreases the number of other fouling organisms as well as of oyster spat which may attach. In some cases a fairly thick sheet of such film has been observed which could be peeled off from the shell. A large shell planting which had become heavily fouled in this manner during the first season was found in the following spring to have the film loosened and peeling off so that by early summer most shell surfaces were comparatively clean and a heavy set of spat occurred. Earlier presence of the film apparently had prevented the attachment of many barnacles during the spring setting period of that organism.

Accurate records of the commercial set of spat on State planted shells in various waters of Maryland have been kept during the past six years. Spat counts were made in late fall after all setting had ceased and when the current year's set had reached a size making the spat readily distinguishable to the naked eye. In a few instances new shell plantings had been placed on the same bar adjacent to a planting of the previous year so that both groups of shells were under practically identical physical conditions of exposure. All instances, ten in number, where the catches of such similarly exposed new and previous year's plantings were counted on the same date have been tabulated. In only one instance was the catch on the older shells greater than on the more recently planted ones and in that case the set was very light on both plantings with a difference of 8 spat. Shells planted during the current year in the cases observed were found to be far more effective than those which had been on the bottom for one year longer, the newer shells receiving an average of 447% of the spat found on the older ones.

A few comparisons were made between shells which had been exposed on the same bar for periods of one, two, and three or more years. It was found that after one year of exposure there was

little or no appreciable decrease in the shell's effectiveness as cultch during the following two or three years. Several instances of good catches on old shells have been recorded but in every case clean shells on the same bar yielded still higher counts. In some instances, deposits of silt as well as the presence of fouling organisms on the shell surfaces, were responsible for the loss in effectiveness as cultch.

Comparative Evaluation of

Commercially Spring Planted Shells

As Oyster Cultch During First and Second Seasons

| Location | Date | Count on current shells | Count on last year's shells | Effectiveness of new over old shells |
|---|---|---|---|---|
| Hungerford Hollow Patuxent R. | 10-17-40 | 14 | 22 | -63.6% |
| Inside Swan Pt. Bar | 10-29-40 | 214 | 42 | 509.5% |
| Parson Island Sands | 11- 1-40 | 2688 | 282 | 953.2% |
| Long Point Choptank R. | 11- 2-40 | 86 | 68 | 126.5% |
| Bald Eagle Rock | 11- 9-40 | 508 | 70 | 725.7% |
| Middleground Nanticoke R. | 11-18-40 | 132 | 38 | 347.4% |
| Middleground Big Annemessex | 11-20-40 | 72 | 50 | 144.0% |
| Lower Thoroughfare Honga R. | 11-23-40 | 144 | 124 | 116.1% |
| Marunsco Pocomoke Sound | 11- 1-45 | 428 | 284 | 150.7% |
| Poplar Island Narrows Swash | 11-28-45 | 146 | 12 | 1216.6% |
| Average of all plantings | | 443.2 | 99.2 | 446.8% |

# DISTRIBUTION OF SETTING GUIDES THE MARYLAND OYSTER PROGRAM

James B. Engle

Aquatic Biologist, U. S. Fish and Wildlife Service

A program to facilitate oyster production is successful only in relation to the reliability of the replacement of the crop removed in harvesting. The whole history of the industry has told a story that demonstrates the truth in this statement. Every oyster producing State on the Atlantic and Gulf Coasts at one time has come to realize that replacement has not been adequate to the demands, and decline in oyster production has been the result. In New England and elsewhere, public control was relinquished to private management with satisfactory results. In Maryland, public responsibility is still retained, and the necessary management is under State control.

All of us here are aware of the simple but essential fact that reproduction and the survival of the young oysters to marketable size must at least equal the harvest. To some degree, this has been ignored and the much worn idea that nature will provide and continue to provide, regardless of how abused, still persists in some places. Nature struggled hard, but found the job too difficult. Another group, many here and many before us, faced by the stark figures of statistics, saw this picture in another light and realized that nature was an ally only when intelligent use of her potentials were considered and applied. In hackneyed but appropriate words, "Nature helps those that help themselves." There are examples of the application of this latter idea in Maryland and in many other places where oysters are produced. Legislation has been formulated to attempt a control of production by safeguarding the supply of young oysters, by regulating the size of marketable oysters, by restricting the taking of oysters during the reproduction and setting periods, and by setting aside adequate spawning and setting areas for seed development. All these factors contribute to the success of oyster production, but the last named is the most significant. I hope I may be able to demonstrate its importance to the Maryland program by a discussion of the setting and seed production of oysters in Chesapeake Bay and tributaries.

Production has slowly declined in Maryland, and a program of management was inaugurated to effect a rehabilitation. Sporadic efforts have been made over many years to stem the diminishing returns in this State, but they have not been very effective because the long range value of the effort was overlooked and the lessons not learned. The present program carefully scanned the previous records and weighed the results. From the analysis, a plan of essentials was devised and first in order was the accepted need for a more complete knowledge of oyster setting in the Bay and tributaries. State and Federal research organizations tackled the problems involved in

answering the many questions of fundamental significance. The research program gave priority to setting, and the results of the studies pointed out several conditions: first, that there was a wide range in the intensity of setting from one place to another; second, there was a tendency for more regularity in setting from year to year in some places than in others; third, there was a definite tendency for setting to be more regular and heavier on the eastern than on the western side of the Bay, (Table 1); and fourth, within the area studied, there appeared to be a tendency for oyster setting to be heavier at the lower parts of the rivers and the Bay than upstream or in the "Head of the Bay" section.

With the above conditions known, the program of stabilization and increase of production was worked out. The oyster areas were now considered under several categories: (1) places where setting was consistent and heavy; (2) areas where setting was adequate for maintaining the oyster population under normal working of the bars when cultch was added; and (3) areas where setting was insufficient to replace the stock of oysters removed during harvesting.

The treatment of the areas in the above categories may now be planned on the basis of shelling bars and transplanting seed. The several places where setting was consistent and heavy were recognized as important for the development of seed production, (Table 2). The seed areas received intensive shelling of approximately 2,000 bushels to the acre annually. The total acreage involved in this phase of the program is still small, mostly limited by the number of shells available and the funds to move them. Three seed areas are now being developed and used, and the progress in rehabilitation and the increase in production will depend largely on the rate at which the seed from these and other seed beds can be produced and transplanted. These three seed areas are strategically located; one in Eastern Bay in the upper part of the Maryland oyster waters; another near Tangier Sound in Holland Straits; and a third in St. Marys River in the lower western portion of oyster producing waters. The search is still on for additional seed areas, and their development will further facilitate the production.

It might be well to point out here that the recent investigations in oyster setting fail to substantiate the idea held in the past that the "Head of the Bay" is a seed area. The results of the setting studies show only occasional sets of any sufficient intensity. The last big setting was in 1931. The accumulation of oysters on the bars of this area is slow, and if any large scale removal of oysters for seed purposes were made, oysters would not be available again for a long time unless an unforeseen and significant setting occurred. This is not a seed area in the true sense of the word because of its unreliability.

Dependable seed areas are essential to the Maryland program for two reasons; first, a large portion of the oyster area does not receive an adequate natural set to meet production demands, yet the social and business economy of the sections rely largely on oystering, so that planting of seed is necessary to keep the oyster bars adequately stocked.

Second, overfishing of the past has seriously depleted many of the bars producing the quality oysters that once made Maryland the oyster center of the world. Shelling alone cannot bring these bars back into commercial production, it will take the planting of many bushels of good seed oysters to reclaim them.

Fortunately for Maryland, there are large acreages of oyster bottom, located mostly in the tributaries, where setting is adequate to restock the bars. The simple method of replacing the cultch which has been removed during harvesting is sufficient to maintain production. The above named sections where seed areas are located fall into this category, as well as Fishing Bay, Tangier Sound, the Choptank River and some of the creeks emptying into it, where there are bars that respond to shelling as the means of maintenance.

Again, the limiting factors in this part of the program are the stockpile of available shells and the funds for transplanting them.

The oyster bars in a large portion of the western shore of Chesapeake Bay, Chester River and the Patuxent River do not have sufficient setting to keep them stocked by natural means. In these sections the seed developed in the seed areas must be planted to insure production. One might ask, "Why is it necessary to make this extra effort to keep oysters on the bars that have such a meager natural replacement?" One of the reasons, the social and business economy of the areas, has already been suggested and is actually important in the Chester River and on the western shore, and another reason is related to the production of quality oysters which can be grown rapidly in the Patuxent River.

Before the results of the research units studying the distribution of oysters were known, planting of shells was considered to be the only operation necessary to maintain any oyster bar, provided adequate adult oysters were present as spawners. Many thousands of bushels of shells were put in these areas with results of negative or dubious value. There is no doubt that the shells had some beneficial value in keeping the bars usable, but as cultch for setting they were wasted. A much better use of the shells could have been made by putting them on seed producing bars and transplanting the seed on these shells to the above bars. The Maryland Department of Tidewater Fisheries, the agency responsible for the management of the oyster resources, now follows the seed transplanting procedure in these cases.

Rehabilitation of the depleted bars, mostly in the southern part of the Maryland waters has not been tackled in a major way as yet because of the shortage of seed, shells and funds. The importance of rebuilding these areas, however, has not been overlooked, and will be actively included in the program when the above shortages are remedied.

Table 1. Total average oyster set on 10 shells taken from test bags placed at the sampling stations in Chesapeake Bay, Chester River and the Choptank River during the setting season of 1946.

Chesapeake Bay Proper

| Eastern side | | | Western side | | |
|---|---|---|---|---|---|
| Station | Total average oyster set 10 shells | Range bottom salinity in o/oo | Station | Total average oyster set 10 shells | Range bottom salinity in o/oo |
| Gum Thicket | 102.0 | 4.67<br>12.81 | Middle Ground | 4.5 | 4.80<br>13.78 |
| Broad Creek | 6.0 | 4.26<br>13.37 | Sandy Point | 3.0 | 3.48<br>12.07 |
| Love Point | 5.0 | 4.27<br>13.65 | Gibson Island | 1.5 | 3.32<br>9.24 |
| Tol-chester | 4.5 | fresh<br>13.91 | Man-o-war | 0 | fresh<br>8.08 |

Tributaries - eastern side

| Chester River | | | Choptank River | | |
|---|---|---|---|---|---|
| Blunts Bar | 8.5 | 5.95<br>12.39 | "B" Buoy | 58.5 | 7.02<br>12.59 |
| Oldfields Bar | 2.0 | 5.70<br>10.28 | Piney Island | 10.5 | 8.71<br>12.59 |
| | | | Kirbys Bar | 0 | 7.65<br>11.29 |

Stations are arranged in the table with the first in the column representing the lower or downstream portion of the area, and the last is the uppermost station.

Salinity range is that of the period of the setting observations with the figure at the top in each pair the salinity of the week of June 15, and the figure at the bottom the salinity of the week of September 15.

Table 2. Oyster spat per bushel of planted shells in designated seed areas.

| Location | 1941 | 1942 | 1943 | 1944 | 1945 Aug. 31, |
|---|---|---|---|---|---|
| | | | | | Oyster spat counts per bushel of shells |
| St. Marys River | 4,534 | 2,560 | 1,342 | 191 | 3,500 |
| Holland Straits-Johnson Pt. | 102 | 175 | 1,454 | 0 | 2,312 |
| Holland Straits-T Creek | 356 | | 661 | | 1,068 |
| Eastern Bay-upper | | 716 | 710 | 39 | 734 |
| Eastern Bay-lower | | | | | 868 |

The Potomac River, now being studied by a joint committee from Maryland and Virginia, may require a treatment combining shelling and seed planting. An examination of some of the bars in the early fall of 1946 failed to show any setting but, at the same time, gave evidence of practically no unfouled shells. Even these fouled shells were in a seriously eroded and crumbly condition. The bars are in need of clean cultch as a first move in restoring them. A study of the setting on the bars in the Potomac River may show that shelling alone will increase the oyster population of this important area.

In conclusion, I should like to repeat that the Chesapeake Bay is a large body of water which has a tremendous potential oyster yield. The actual production has been greatly reduced, but the management has in the past tried to get along with very little knowledge of the biology and ecology of the oysters on the bars. That the Bay may be returned to a substantial portion of its earlier production is the aim and belief of all of us, providing we continue the search for the fundamental principles that control the reproduction and apply them to the program of management.

## OBSERVATIONS ON OYSTER DRILLS:

## CHROMOSOMES OF *UROSALPINX CINEREUS*, SAY

Dr. H. Malcolm Owen

Biologist, Louisiana Department of Conservation

The Atlantic Coastal distribution of *Urosalpinx cinereus*, the oyster drill, shows definite delineations as to the size of the individuals. The physical environmental conditions do not correlate to the size of the individuals.

A cytological study of the maturation of the male gonads shows, however, that the chromosome number is constant, it being $2n = 32$.

A distinct chromosomal behavior characteristic was noted in the smaller sized drills, which was not found to be present in the larger individuals of a different geographical location. In all cases during Anaphase I of the small drill one chromosome lags behind the other chromosomes, forming a distinct chromosomal bridge.

It was therefore concluded that Henderson and Bartsch (1915) were correct in recognizing two races of the species.

(An abstract by the author - the full text of the address was not available.)

THE PROS AND CONS OF INTRODUCING FOREIGN SHELLFISH

Dr. Thurlow C. Nelson

Professor of Zoology, Rutgers University

At our Convention a year ago some possible advantages to be derived from the importation of foreign species of oyster were presented, together with the urgent need of restricting wholesale and uncontrolled admission of shellfish from distant shores. Dr. Radcliffe, following this meeting, appointed a committee, consisting of Doctors A. E. Hopkins, Gowanloch and your speaker, to consider all possible angles of this problem and to report back to this Association.

It has not been possible for your Committee to meet as a body, but through considerable correspondence, we may now present for your consideration some of the arguments for and against such importation. Since this is to be a round-table discussion, my remarks will be brief, and I hope, to the point.

A. Evidence favoring importation of foreign oysters.

1. Stunted oysters, designated by the British as "dumpy" or as "dumps" grow exceedingly slowly, some individuals 10 to 12 years of age being no larger than normal 2-3 year old oysters.

2. Depleted oyster beds nearly always show a high percentage of such dwarfed individuals. Where the 3-inch law prevails as in Chesapeake Bay, the faster growing oysters are continually being removed while the dumps are returned. On some planted grounds these dumps are the culls, too small to market, which are thrown back on a portion of the bed. Within the past four weeks Dr. Carriker and your speaker shucked more than 1000 oysters at a meeting of our University Outing Club. Not more than a dozen of these were strong vigorous bivalves, the rest were dumps. Some of them 8-12 years old were barely large enough to warrant shucking. Why did we, oyster scientists with a reputation to maintain, shuck such poor stock? The answer: it was May 11, the owner had no objection to disturbing these oysters, they had no spring growth to speak of. They were the rejects of years----too small to command a price.

3. While no scientific proof exists that crossing of strains of oysters produces superior stock, the fact remains that among the most successful oyster producing areas today are those to which oysters are continually being brought from other regions.

4. Hybridization of farm crops and animals has yielded large financial returns to agriculture. We need mention but two: hybrid corn and the mule, which between them yield added annual income to this country of many millions of dollars. Other hybrids too numerous to mention have been made, particularly among flowers, of added value of millions more.

5. Among the most desirable results of hybridization is increased vigor which expresses itself in more rapid growth and frequently larger size. We do not want a larger oyster on this coast; our consuming public has very definite ideas on what it will eat for half shells, for stews and for fries. But why should it take up to six years or longer to produce a select or extra select in the three best oysters of the world; our Atlantic coast oyster, species virginica; the European oyster, species edulis; and the Australian oyster, species cucculata? The Pacific oyster or so-called Jap oyster, species gigas, may attain a size better than a select within two years or less. Such growth in oysters, therefore, is possible; it has occurred on our shores in the Northwest.

6. Although oysters have not yet been crossed, this is no argument for not attempting it. Where would our farmers be now in these days of high cost of labor, equipment, and supplies were it not for their superior strains of domestic animals and plants? If oysters are to continue to compete with other food products, the cost of production must come down. Every year which can be cut from the time necessary to mature a crop of oysters means quicker turnover of capital, reduced losses from enemies, from storms and natural mortality.

7. Oysters fall into two groups with respect to their critical spawning temperatures. In Group A, to which belong our own Atlantic oyster, the Portuguese and the Jap oyster, spawning does not usually occur until temperatures above 68° F. or 20° C. have been maintained for some time. From Delaware Bay, south to the Gulf, there is good evidence that this critical temperature may be 25° C., (77° F.). Even the temperature of 20° is above that existing along most of our Pacific coastline and on the Atlantic, north of Cape Cod.

In Group B are those oysters which, like the Olympia oyster of our west coast and the European oyster, incubate the young on their gills. The critical spawning temperature in these oysters is 15° C. or 59° F. This lower temperature opens much of the north European coast to Ostrea edulis which in the oyster pools of Norway breeds even within the Artic Circle. Although slow growing, this is a superior oyster which in England has brought the highest price paid anywhere in the world for oysters; a shilling apiece for the finest Colchester Pyefleets. It thrives best in clear water of near oceanic saltness, the very conditions which obtain from Cape Cod to Maine.

Because of its different life cycle, there is practically no likelihood whatever that the edulis oyster would hybridize with our own Atlantic oyster. North of Cape Cod it would not even have the opportunity. If, however, favorable conditions were found there, a new and valuable oyster fishery might be established there.

The small Olympic oyster is now America's most expensive shellfish. Since its breeding habits are the same as those of the much larger edulis of Europe, a hybrid between these oysters should be of great value. Both have excellent flavor, but both are slow growing. In addition, the Olympic oyster is very sensitive to frost. A hybrid between them should grow much faster than either, and some of the cold hardiness of edulis might replace the sensitivity of the little Olympia oyster.

B. As against the importation of foreign oysters must be urged:

1. The dangers of importation of enemies. The introduction of the mud-worm, Polydora ciliata, into Australia about 1870 drove the entire oyster industry off the bottom. All oysters are now grown attached to stakes or slabs of stone. Can you imagine such a revolution in methods of culture here, particularly in Long Island Sound? Some of our own Polydora have been identified as P. ciliata though no one to my knowledge has actually compared our species side by side with those from Australia and proven their identity.

   Our own "double decker" Crepidula, known to the British as the "slipper limpet", grows to giant size in English waters. In competition for food it has proven more than a match for the rather particular and somewhat less vigorous European oyster Ostrea edulis. We never know beforehand how any animal or plant will behave when introduced into a new area.

2. If a hybrid oyster were produced, but turned out to have objectionable qualities, it could readily become a serious pest. Like the black mussel, which has great vigor, an undesirable hybrid oyster might soon cover up and smother our best oyster beds with a very inferior, even unsalable substitute. I consider the Portuguese oyster, species angulata, as approaching that category. In England in 1931 I had no difficulty in fertilizing the eggs of our own virginica with the sperm of angulata and in obtaining swimming young. Whether larvae of setting size might be obtained is not known.

From what has been said, it follows that we must proceed with caution. Unrestricted and uncontrolled importation of foreign shellfish must not be permitted to our Atlantic or Gulf states. Where state laws are lacking or inadequate to control the situation, federal restrictions may temporarily be needed.

## ON THE IMPORTATION OF FOREIGN SHELLFISH

Report of Committee Appointed by Dr. Radcliffe for the Association

The following resolution was accepted at a joint meeting on Tuesday, June 7, 1946, of The Oyster Growers and Dealers of North America, Inc., The Oyster Institute of North America, and the National Shellfisheries Association:

"Whereas, considerable risks would be involved in uncontrolled introduction of nonindigenous species of oysters, including the possibility of introducing other enemies of oysters, into production areas along our Atlantic and Gulf coasts; and

Whereas, agriculture has benefited by many millions of dollars from scientific research in selective breeding and the development of new strains of domestic animals as well as better grades of cereals and other crops,

Therefore, be it resolved that the introduction of new species of oysters into the waters of the Atlantic and Gulf coasts be adequately safeguarded by requiring permits of the State Shellfish Commission or other competent agency fully conversant with the risks involved; and then only after comprehensive studies have been made and definite assurance given that such action is warranted; and

Be it further resolved, that Federal and State and other research agencies be urged to undertake scientific researches intended to effectuate improvements in the strains of native oysters and studies of nonindigenous species of prospective value to determine probable benefits to be derived from such introductions; and

Be it further resolved, that the several Atlantic and Gulf coast states be urged to pass legislation to effectuate the above purposes."

It is the opinion of your Committee that this resolution embodies adequate safeguards for the protection of the oyster industry while leaving the way open for research aimed at two primary objectives; (1) faster growth; and (2) the introduction of species capable of reproducing in the cold waters of the northeastern Atlantic and the Pacific. The time has come when we must develop our coastal waters to a much greater degree for the raising of food. We should be derelict in our duty if we failed to encourage and to undertake ourselves the research necessary to establish a basis for action.

In those states in which competent biologists are located, it should be possible to control the problem adequately by state laws. States not having the benefit of such advice would do well to prohibit altogether the importation of foreign shellfish though leaving open to university or federal laboratories the opportunity to import such species under license.

The New Jersey law is cited as an example.

"Article 6. PLANTING OF FOREIGN OYSTERS OR SHELLFISH.

50:1-34. Permission to plant foreign shellfish; application and contents. No oysters, seed oysters, or other mollusks, commonly known as shellfish, native to, or brought directly or indirectly, from any foreign country shall be planted or lodged in the waters of this state without written permission issued by the board for each separate shipment. Application for such permission shall be made in writing, and shall state:

a. The species of such oysters, seed oysters or mollusks;

b. The location from which they were, or are to be, immediately taken;

c. The source from which they were originally obtained; and

d. The country to which their kind is native.

The same information shall be shown upon a tag attached to, or upon the billing accompanying each shipment upon its arrival in this state.

Source. L. 1933, c. 345, 1, p. 901.

"50:1-35. Permission granted; prerequisites; form. The board may issue such permission after due inspection and examination of the nature, species, quantity, source, location of proposed planting

or lodging, and the condition of the oysters, seed oysters or mollusks, and after certification by the biologist of the board that the same will not, in his opinion, be detrimental to the native oysters, or to the oyster industry of this state.

Such permission shall specify the nature, species, quantity and proposed location of planting or lodgment of the oysters, seed oysters or mollusks and shall apply only to the particular shipment for which it is issued.

Source. L. 1933, c. 345, 2, 3, pp. 901, 902.

"50:1-36. Costs. The board shall make such charge, and collect in advance, for the issuance of such permission, such sum of money as may be necessary to defray the cost of the inspection, examination and certification.

Source. L. 1933, c. 345, 4, p. 902.

"50:1-37. Penalty for violation; revocation of license. Any person or corporation who shall, without such written permission aforesaid, plant or lodge in the waters of this state such oysters, seed oysters or mollusks, shall be liable to a penalty of one thousand dollars recoverable in an action at law in any court of competent jurisdiction brought in the name and for the benefit of this state by the attorney general at the instance of the board.

The board may, in addition to such penalty, revoke the license of any boat or vessel, licensed under the laws of this state, used or employed in the planting or lodgment, without such permission, of any such oysters, seed oysters or mollusks, and may also cancel the lease of any person or corporation who plants or lodges, without such permission, any such oysters, seed oysters or mollusks, upon any lands under water leased from this state.

Source. L. 1933, c. 345, 5, p. 902.

"50:1-38. Shellfish affected. This article shall not affect the planting or lodgment in the waters of this state of any oysters, seed oysters or mollusks, commonly known as American or Eastern oysters, and scientifically known as Ostrea virginica Gmelin, but shall be construed to affect the planting or lodgment of all other species.

Source. L. 1933, c. 345, 6, p. 902."

# SEASONAL CHANGES IN THE FATTENING OF OYSTERS

Dr. Walter A. Chipman, Jr.

Aquatic Biologist, U. S. Fish and Wildlife Service

More and more attention is being placed on the production of oysters with high quality meats. So often are we called into an area to investigate the failure of oysters to fatten properly and give a good yield that consideration must be given as to what is involved in this fattening process.

Oyster meats may be considered as being composed of water, carbohydrates, fats, proteins, and the mineral salts. In general, oysters are considered as a protein food, but large amounts of carbohydrates at times make them even more valuable as food. The importance of the mineral content must not be overlooked.

True fattening of oysters is reflected in a low water content and a high carbohydrate content. Changes in protein and fat are not of particular importance in fattening. This accumulation of carbohydrate reserve is almost entirely in the form of glycogen, or animal starch. It is to be regarded as a reserve material stored up for the carbohydrate needs of the organism, in this respect playing an analogous role to that of starch in plants. As the carbohydrate requirements of the organism vary, so does the quantity of glycogen present fall or rise. In case of need, it is apparently converted mainly into glucose, and ultimately undergoes complete hydrolysis and oxidation. Rise of temperature, increased functional activity and diminished food supply are the chief factors which may produce a reduction in the amount of glycogen present in the oyster.

An oyster lacking in all reserves gives the appearance of consisting merely of skin and water. This condition is approached after spawning, but there is usually rapid recovery. Failure of oysters to store reserve material again and to become as plump and firm as may be expected does not occur too frequently, but does to an extent that merits attention as to possible causes for this deficiency.

Although the present paper deals with seasonal changes in the fattening of oysters, it should be borne in mind that there is considerable variation in the fatness of individual oysters on an oyster bed, between oysters of different locations, both in the immediate vicinity and in widely separated areas, and among the same oysters at different times.

There is, of course, an important relation between the periods of spawning and the subsequent fattening, but the great variety of conditions for fattening said to occur within a short space in a

given locality requires investigation. It seems probable that an adequate food supply for fattening is rarely absent from good oyster beds and that this factor has been overemphasized. While it is true that the period of active feeding must coincide with a good supply of food material in order for the oyster to store up food reserve, other factors, particularly those involved in the metabolism of the oyster, its anabolism or catabolism, and changes in these by outside forces, need more attention.

In the course of studies made throughout a number of years, rather extensive information has been collected on the chemical constituents of oysters from a number of localities, particularly of the glycogen content. Oysters have been analyzed from Long Island Sound, various localities in the Chesapeake Bay, particularly in the lower Chesapeake Bay, the Piankatank, York, and James Rivers, and a few samples from South Carolina, Texas, and other points. A number of these analyses were made on oysters known to be in poor condition from some cause, and, in some instances, the examinations were not made a sufficient number of times throughout the year to give evidence of any seasonal change, since the experiments were designed to fit other purposes. However, considerable material has been collected from certain beds over sufficient times to warrant analysis as to changes in fatness through the different seasons of the year.

The samples of oysters were opened and, after the shell liquor was discarded, the meats were drained of excess moisture, and ground to a fine state. Samples of the meats were dried for determination of the total solid content, and other samples analyzed for glycogen, using the usual methods of digestion with hot alkali, precipitation of the glycogen with alcohol and purification of this precipitate, and, after conversion to sugar, measuring of sugar content of the sample by an accurate titration method. The results are presented showing the percentage of glycogen in the dried oyster meats. Since there was no measurable loss of glycogen in the draining of the meats, differences in the method of draining in the different years had no effect on the results.

If we examine the curves shown in Figure 1, it can be clearly seen that the accumulation of glycogen in the oysters follows a definite seasonal pattern, as has been pointed out so many times in the work of investigators for many years past. There is a period of very low glycogen in the late summer, which is followed by an increased storage of glycogen in the fall and early winter until the time of hibernation. The period of high glycogen is followed by a sharp decrease in the spring as the oysters resume their activity and spawn, reaching a low glycogen reserve again after spawning.

The curves of glycogen content of oysters collected from various localities are of the same pattern, but differ quantitatively. The oysters from Long Island Sound appear to build up glycogen reserve earlier in the fall than do the oysters from the lower Chesapeake Bay. It should be pointed out that fattening of oysters has barely started in September when the oystering season begins, and that the same oysters would be fatter and give a much greater yield if marketed in November and December. This is more marked in the oysters of the Chesapeake Bay than those of Long Island Sound.

Fattening of oysters from the same beds differs from year to year. This is readily seen in Figure 2, which shows the percentage of glycogen in the dry meats of oysters from Long Island Sound examined in different years. It will be noted that the accumulation of glycogen in 1933-34 was much greater than in 1932-33 and that the loss of glycogen in the spring of 1934 was not as early as in 1933. The failure of certain beds to produce as fat oysters in one year as in another has long been a problem that needs more careful study.

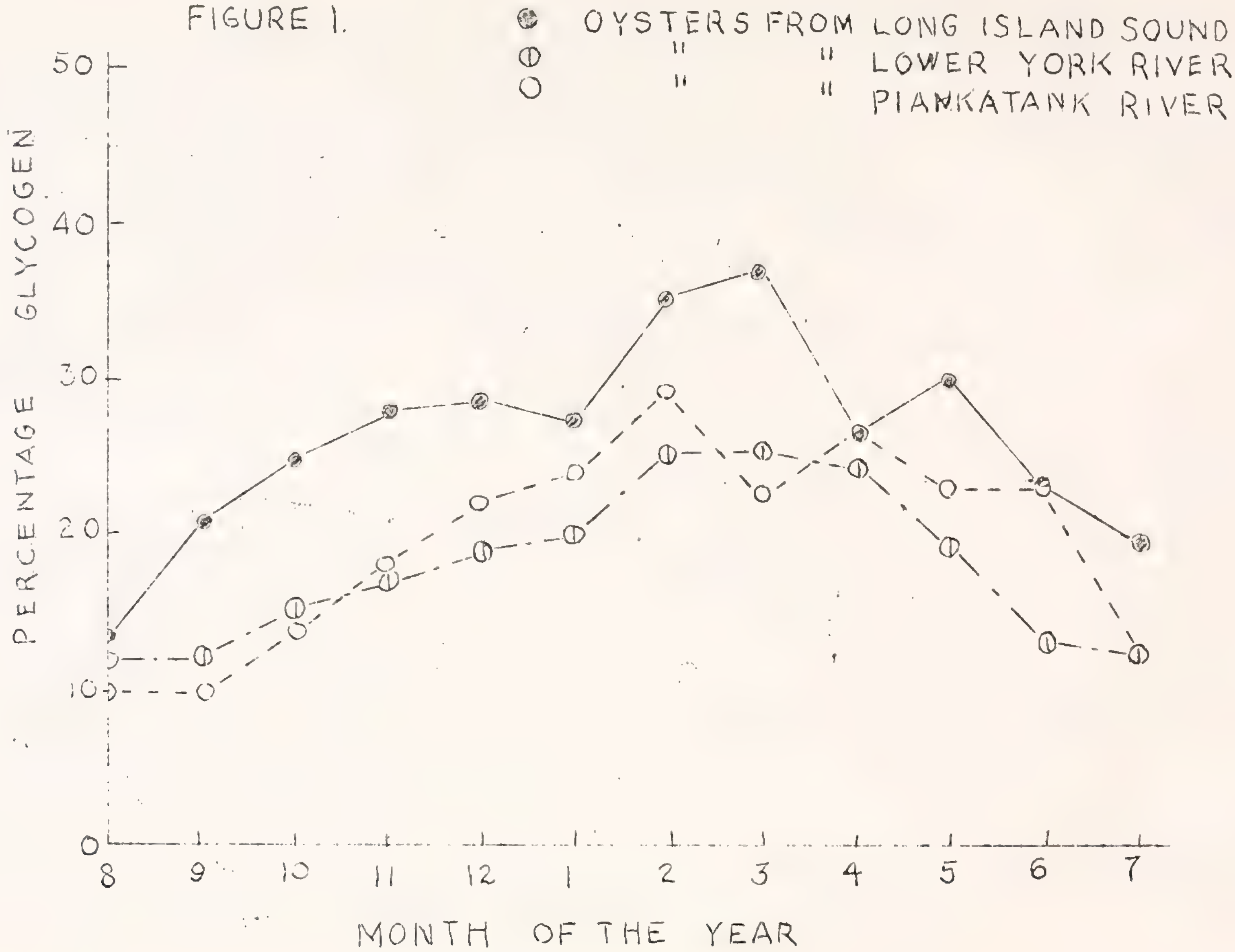
Condition of the water, such as low temperature and abnormal salinity during the spring, may alter the formation of the reproductive elements, and with this change in the development of the sexual maturity of the oysters, there may follow a retention of the glycogen reserve later in the year. This may explain why the fatness of oysters may be longer continued in some years than in others.

Emphasis should be placed on the condition of the water, the abundance of food, and, perhaps, the type of food available during the late summer when the oysters are the most active and are vigorously feeding. This is the most critical time of the year as regards fattening as it is this time that reserve glycogen is being stored. If the oysters fail to fatten during the late summer and early fall, they will not be fat at any time during the year, for there is not any appreciable increase in glycogen reserve during the colder months.

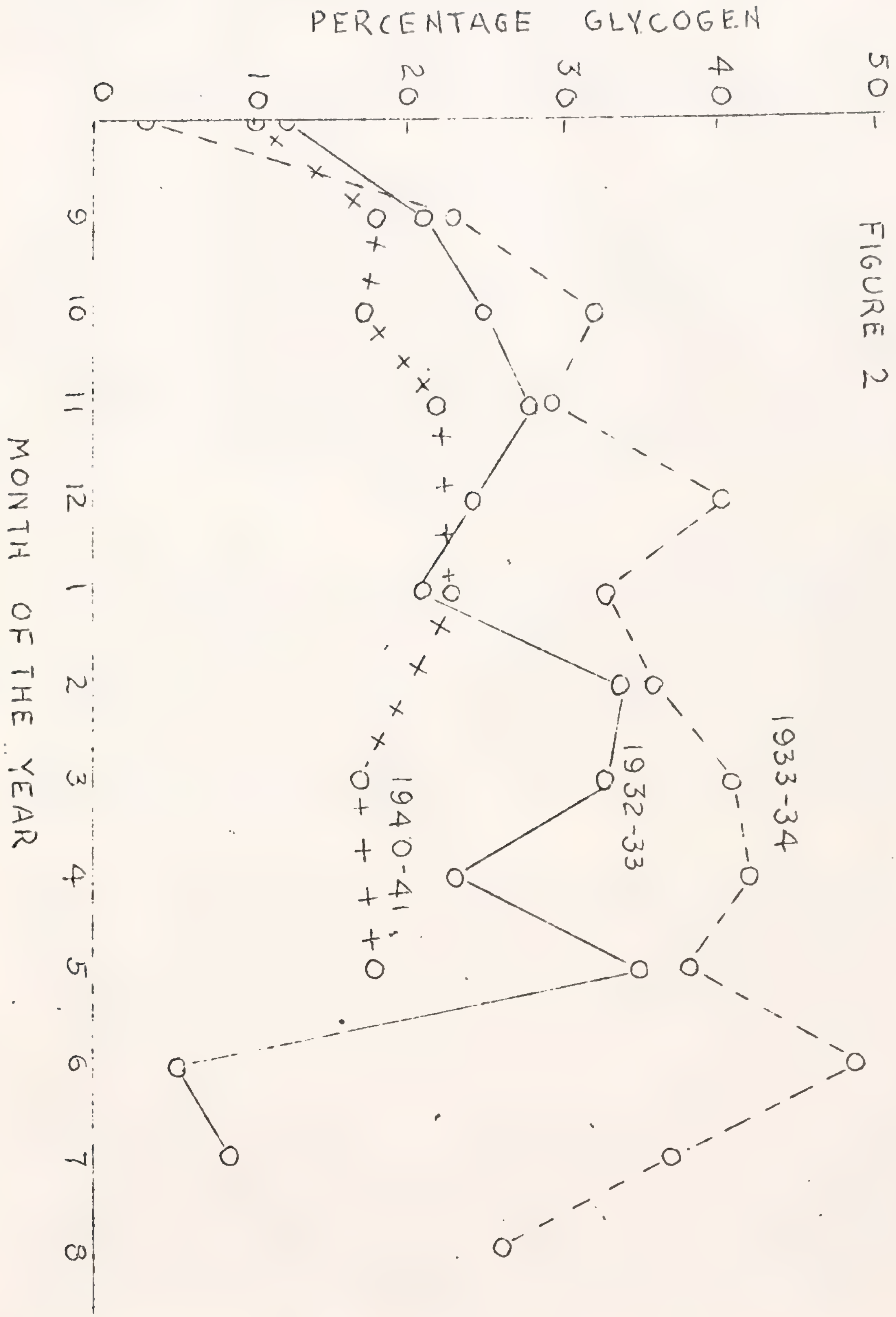
It is generally considered that good fattening grounds often differ from good producing grounds and good growing grounds. Very often a good stiff mud bottom, close inshore and protected from excessive current action, will prove to be an excellent fattening ground, and oysters produced on other beds, or grown on other beds characteristically good for oyster growth, are transplanted to these fattening grounds to prepare them for market. When oysters transplanted to the fattening grounds fail to fatten properly and give a good yield, one must consider the possibility that this failure may well be due to one or more of the weakening influences incurred in the transfer of the oysters.

Outside factors regulating the fattening of the oysters, such as water temperature, salinity, currents, availability and type of food, bring about this regulation by changing or altering the inner activities or physiological activities of the oyster itself. Changes in the salinity, alkalinity, and chemical nature of the water, as well as the physical conditions of temperature and turbidity, both from silt and abundance of microorganisms, play an important part in the regulation of the opening and closing of the oyster, the amount of water passed through the gills, the muscular activity, respiration, and the other vital activities of the animal. It is through a study of the metabolism and physiology of the oyster, under both normal and abnormal conditions, that we can interpret the mechanisms of fattening and the loss of this carbohydrate reserve. It is to this end that our studies are being directed.

FIGURE 1.



OYSTERS FROM LONG ISLAND SOUND
" " LOWER YORK RIVER
" " PIANKATANK RIVER
PERCENTAGE GLYCOGEN
50
40
30
20
10
0
8
9
10
11
12
1
2
3
4
5
6
7
MONTH OF THE YEAR


PERCENTAGE GLYCOGEN
0
10
20
30
40
50
MONTH OF THE YEAR
9
10
11
12
1
2
3
4
5
6
7
8
1933-34
1932-33
1940-41
FIGURE 2

# RESPIRATION IN OYSTERS.

Dr. Paul S. Galtsoff

Aquatic Biologist, U. S. Fish and Wildlife Service

Breathing or respiration is the principal function of every living thing. Fundamentally, it consists in the burning of food materials ingested or stored in the organism. It can therefore be measured by determining the amount of oxygen consumed per unit of time and the amount of carbon dioxide produced in oxidizing the food substances. The ratio of the $CO_2$ produced and the oxygen consumed is called the respiratory quotient or R. Q. The numerical value of R. Q. may be used to indicate the relative amounts of food materials used as fuel in the body. If carbohydrates only are being burned the R. Q. is 1.0. Protein gives an R. Q. of about 0.8 and fat 0.7. The R. Q. values exceeding 1.0 indicate that additional amount of carbon dioxide is liberated from other sources--probably from the bicarbonates of the blood.

Chemical changes in the organism which provide energy for vital processes and activities are called metabolism. The gas exchange between the organism and the surrounding water or air is one of the most important parts of the metabolic processes. The rate of such exchange, determined when the organism is at complete rest, is known as "basic metabolism"; it represents the minimum requirements necessary to sustain life. Its determination in human beings is frequently made by the physician in the course of his search for the cause of an ailment affecting his patient. Physiological literature contains numerous data on the metabolism of man and higher animals in health and disease but comparatively little is known about the metabolism of lower forms.

When the receding tide leaves the seashore exposed, many of the marine organisms inhabiting this zone withdraw into their tubes and burrows, or tightly close their shells and suspend many of their vital functions. The oyster is one of these animals of the tidal zone capable of remaining inactive for hours and days. When it closes its shell and stops ventilation of the gills, the ciliary motion of the gills and mantle ceases and respiration is suspended. The heart beat becomes slow and irregular and there is no exchange of gases and other products of metabolism between the body and the surrounding water or air. The limited reserve of oxygen in the shell liquor and in body fluids and tissues is used up and the organism incurs an "oxygen debt" which, as we shall see later, should be "paid" when the shell opens again and normal functions are resumed. It is therefore impossible to speak of the basic metabolism of an oyster in the sense the term is applied to mammals. The minimum requirements of an oyster for oxygen can be determined, however, under certain specified conditions, namely, when the oyster maintains a steady ventilation of its gills by pumping through them a current of water containing neither food nor any irritating substances.

We know that physical exercise increases our rate of breathing. Likewise, the oyster consumes more oxygen when its shells move more frequently than when they remain steady or are brought together only occasionally. In conducting a metabolism test in oysters, it is therefore necessary to avoid conditions which may cause excessive shell movements and thereby increase the consumption of oxygen. This can be attained by selecting healthy oysters and keeping them at a constant temperature in filtered sea water which contains no food and is free of any pollutants which may stimulate the highly sensitive neuromuscular system of the mollusk. Furthermore, shell movements of the oyster must be watched all the time when the test is made, because no oxygen is consumed while the valves are closed. The failure of previous investigators to observe these precautions leads to great confusion in interpreting their data.

The old method consisted in placing the oysters in a small closed container filled with sea water and determining its oxygen content at the beginning and at the end of the test, paying no attention whether the oysters were open or closed. The results of such experiments are erratic and unpredictable.

The more accurate test of oyster metabolism, used in the present investigation requires a rather complex apparatus. It consists of a large supply of filtered sea water which is run through a small chamber in which the oyster is kept. By testing the water before it enters the chamber and after it has passed through it, it is possible to compute the amount of oxygen removed by the oyster in a given period of time. The rate of flow of water is regulated by a constant head and the temperature is kept at a desired degree. Oysters are starved for 24 hours before beginning the experiment to avoid the effect of feeding. Their shells are thoroughly scrubbed to remove all organisms attached to them, and after that they are painted with melted paraffin.

The tests, made only with adult oysters of marketable size, were designed to answer the following questions: (a) what is the minimum requirement of oxygen for an adult oyster, (b) are there significant changes in oyster metabolism during various seasons of the year, and (c) are there significant differences in the respiratory quotient of oysters of different sex and during different seasons.

In order to determine whether there is a significant change in the rate of metabolism during the various seasons, each oyster used in the test was marked by engraving a number on its shell and was kept in sea water either in a live box suspended from the pier in the harbor or in a large outdoor tank filled with sea water. Regardless of the season, the rate of $O_2$-intake was determined at the temperature of about 25°C. Records were obtained for eleven oysters which were tested at various intervals from July 1940 to

July 1941. From the results of these tests summarized in Table 1 and from observations on other oysters presented in Table 2, two inferences can be drawn: First, that the minimum oxygen requirement of an adult oyster under the condition of the experiment varies from 1.1 to 5.8 cubic centimeters of oxygen per hour. Secondly, that oxygen consumption during the fall and winter months is less than during the summer. Additional observations were made to find the reason for these changes in the metabolic requirements. It was found that there was a marked decrease in the rate of oxygen intake immediately after the completion of spawning. The data summarized in Table 2 clearly indicate this trend. It is known that in spawning the oyster loses a considerable portion of its solids which are replaced by water. This undoubtedly is the principal cause of the reduction in the rate of $O_2$-consumption by individual oysters.

In several instances the oysters spawned during the test, while they were still in the metabolism chamber. Each time this happened the rate of oxygen consumption immediately increased by as much as 41% due to the presence of the discharged sex cells in the water. From this observation inference is made that the oxygen demand of the sex cells inside the gonad is much less than after their release from the body.

Loss of gonad material is not the only cause for the decreased metabolic rate during the fall and early winter. We know that this is the period when oysters accumulate reserve material and fatten. It is reasonable to assume, therefore, that a low metabolic rate is somehow associated with the storage of glycogen because it is generally true for all animal forms that a gain in the weight of their bodies results from the failure of the organism to burn the supply of food which it consumes. I hope that our further investigations will throw light on this interesting phase of oyster metabolism which is closely related to fattening.

Under stable conditions of the environment, i.e., when the temperature, salinity and pH of the water remain constant, the intake of oxygen by individual oysters continues at a steady level for a long period of time.

A decrease in the pH reduces the oxygen consumption, and at pH 5.5 respiration slows down to less than 10 percent of its normal rate.

A sudden decrease in the salinity of water from 31 to 24 o/oo resulted in an increased oxygen consumption. Whether this effect holds true for the greater change in the concentration of salts will be shown by further experiments which are now in progress.

The respiratory quotient (R. Q.) was found to fluctuate from 0.7 to 1.2 with no significant correlation with the sex of the oyster or the season of the year.

Oysters which were kept for a long time out of water show an increased demand for oxygen during the first hour of the test. This is due

to the depletion of the oxygen supply in their tissues--the so-called oxygen debt. After the demand for $O_2$ is satisfied, the intake of oxygen falls to its normal level.

Several conclusions of practical value to the oyster growers can be drawn from these studies of respiration. Since the oxygen demand of oysters is greater during the spawning season, an additional supply of oxygen, greatly in excess of the normal requirements of adult oysters, is needed for the spawn. It is, therefore, important that in selecting the spawning grounds the oyster growers are certain that the water near the bottom is well oxygenated.

After the oysters are removed from water and kept in the air for several days, their metabolic rate is greatly increased to satisfy the incurred debt of oxygen. This fact should be kept in mind when oysters are conditioned for the market in purification or storage tanks which are frequently overcrowded and the water thus is subject to oxygen depletion.

An increased acidity of sea water measured by the decrease in its pH value reduced the rate of respiration and creates conditions unfavorable for oyster metabolism. Acid conditions on oyster bottoms may be caused by overcrowding, fouling of shells and pollution of water by chemical wastes.

Oysters of good quality cannot be produced in the waters containing substances which suppress their normal rate of respiration. Likewise, good, fat oysters are not expected to be found in waters contaminated with trade wastes or other materials which irritate their neuromuscular system and cause increased shell movement. The presence of these foreign substances in natural waters increases the oxygen demand of oysters and results in the burning up of reserve material in their meat. Oysters grown under these conditions fail to fatten and are generally poor.

TABLE 1. -- Seasonal changes in the oxygen intake of adult Long Island oysters about 10 cms. long and 7 cms. wide. All tests made at 25°C. Oysters 50-62 were tested in 1940 at Woods Hole. All other tests made at Milford, Connecticut.

| OYSTER NUMBER | July | Aug. | Oct. | Nov. | Dec. | Jan. | Feb. | March | Apr. | May | June | July |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 3.51 | 2.92 | | | 1.8 | | 1.8 | 1.6 | | | 1.4 | 1.9 |
| 51 | 2.69 | | | | | | 2.0 | | | | 1.5 | |
| 52 | 2.45 | 1.08 | 1.25 | | | 1.3 | 1.7 | 1.1 | | | 1.2 | |
| 53 | 3.08 | | | | | | | 2.5 | | | | |
| 55 | 3.65 | | 2.10 | | | 2.5 | | 2.8 | | 1.9 | 3.3 | 3.0 |
| 56 | | 2.86 | | 1.7 | 2.2 | | | 2.0 | | | 3.1 | 2.0 |
| 62 | 3.28 | | 1.8 | | | 1.4 | | 2.2 | | | 3.8 | 3.0 |
| M-1 | | | | | 2.4 | | 1.8 | 1.6 | | | | |
| M-4 | | | | | | 2.4 | | 2.7 | | 2.7 | | |
| M-6 | | | | | | 2.9 | | | | 2.8 | 3.1 | |
| M-9 | | | | | | | 2.1 | | 2.2 | 2.4 | | |

(Editor's note:- No records were noted for September.)

TABLE 2. -- Mean $O_2$-intake, in ml per hour, per oyster, determined in July, before spawning, and two weeks and 1 month after spawning. The figures are the mean values computed from 6 observations made at half an hour intervals.

| TIME OF OBSERVATION | OYSTER NUMBER 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before spawning July | 4.29 | 3.39 | 3.00 | 5.13 | 4.01 | 2.53 | 5.84 | 4.89 | 3.11 | 3.64 | 5.17 |
| Two weeks after spawning August | 4.73 | 3.02 | 2.84 | 3.89 | 3.21 | 3.10 | 4.11 | 4.00 | 3.08 | 2.78 | 5.10 |
| One month after spawning August | 3.96 | 2.38 | 1.93 | 3.39 | 2.26 | 3.03 | 2.95 | 3.12 | 2.53 | 2.23 | 4.37 |

TABLE 3. -- Oxygen intake in ml $O_2$ per hour of adult oysters from Long Island Sound, about 10 cms long and 7 cms wide, determined in July, before spawning. t° - 24-25°C. Nos. 4,8, and 11 are females, the others are males.

| HOURS AFTER START | OYSTER NUMBER 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 4.52 | 1.79 | 2.93 | 5.07 | 3.90 | 1.97 | 6.31 | 4.80 | 3.62 | 3.73 | 4.76 |
| 1.0 | 5.42 | 2.83 | 2.97 | 5.07 | 4.21 | 2.48 | 5.69 | 4.69 | 3.28 | 3.80 | 4.85 |
| 1.5 | 4.28 | 3.00 | 2.90 | 5.18 | | 2.00 | 5.69 | 5.04 | 3.79 | 3.66 | 5.15 |
| 2.0 | 4.17 | 3.21 | 2.86 | 5.14 | 4.00 | 2.69 | 5.90 | 4.83 | 3.07 | 3.38 | 5.35 |
| 2.5 | 4.04 | 3.66 | 2.97 | 5.24 | 4.07 | 2.97 | 5.59 | 5.07 | 2.93 | 3.52 | 5.71 |
| 3.0 | 3.93 | 3.86 | 3.35 | 5.14 | 3.97 | 2.86 | 5.83 | 5.24 | 3.04 | 3.73 | 5.44 |
| 3.5 | 3.69 | 3.76 | | 5.04 | 3.93 | 2.79 | | 4.59 | 3.07 | | 4.92 |
| MEAN | 4.29 | 3.39 | 3.0 | 5.13 | 4.01 | 2.53 | 5.84 | 4.89 | 3.11 | 3.64 | 5.17 |

EFFECTS OF TURBIDITY ON FEEDING OF OYSTERS

Dr. Victor L. Loosanoff

Aquatic Biologist, U. S. Fish and Wildlife Service

Our oysters are shallow water mollusks normally living in gulfs, bays and harbors in which rivers and creeks discharge their waters. Because of the differences in river discharge the conditions in such brackish bodies of water may vary a great deal within a short period. To meet such changeable conditions nature endowed oysters with the ability to withstand rather wide changes in their environment. We already know of the ability of oysters to survive sharp changes in temperature or salinity, and may predict with reasonable accuracy how such changes would affect the oysters. However, there are several other factors in oyster environment, which are considerably affected by river discharge, but of which we have a rather limited knowledge. One of these is turbidity.

A discussion of the effects of turbidity upon oysters is of especial interest to a large group of oyster growers because many of their cultivated beds may be sometimes included within the areas the waters of which are rendered turbid by man's activities. In other words, besides the turbidity which is caused by large quantities of inorganic and organic substances brought down to the estuaries of the rivers, such as the Mississippi, we may face conditions when the waters of oyster-producing areas are made turbid by the dredging of channels or by other operations in which the upper layers of bottom soil are disturbed. Naturally, it is of interest to all of us to know how different concentrations of turbidity-creating substances in the water affect the oysters, or at least some of their activities.

Quite extensive studies of the gross effects of dredging and resulted turbidity upon oysters were made by G. R. Lunz, Jr., for the U. S. Engineers' Office in 1936. Dr. Lunz concluded that the dredging operations conducted in the Intracoastal Waterway of South Carolina "were not injurious to oysters and killed only those actually buried by spoil". He also concluded that dredging operations did not affect or influence the spawning and setting of oysters, and that "no connection can be found between the yield of ounces of canned oyster meats per bushel and dredging operations.....".

Judging by Lunz' results one may conclude that oysters remain to exist almost undisturbed in water the turbidity of which is greatly increased. There is no doubt that Dr. Lunz' observations were correct for the area where he did his work. However, his conclusions are somewhat contradictory to the findings of Kellogg, Yonge, and to a large extent to our own, namely, that oysters, as well as other closely related mollusks, are primarily clear water inhabitants and that they

can feed most efficiently only when the water is relatively free of solid particles. Therefore, to verify at least some points of the question in dispute we thought it desirable to determine how different concentrations of turbidity-making substances would affect the rate of water pumping and, therefore, the feeding of oysters. Several years ago we began to experiment at Milford Laboratory and now certain results of our work may be reported and some deductions made. I would like to take the opportunity to express my appreciation and thanks to Miss Frances Tommers, who so ably assisted throughout these studies and to my colleague, Mr. James Engle, who participated in the early stages of the work.

Our experiments consisted in observing the changes in the rate of feeding and shell movements of the oysters when the concentrations of turbidity in sea water were changed. We used from 0.1 gram to 4.0 grams of turbidity-creating substances per liter of water. In the first series of experiments fine silt collected from the tidal flats of Milford Harbor was used. This silt was placed in suspension in the water and filtered through a fine net. Later the heavy sediment consisting mostly of sand particles was discharged, while the lighter portion was dried and pulverized. During the entire series the silt of the same batch was used. At the beginning of each experiment the needed quantity of silt was taken from the air-tight jar and placed in a vessel containing the necessary quantity of water and then stirred until all the particles of silt were in fine suspension. In addition to natural silt we used a clay-like substance - kaolin (aluminum silicate), chalk (calcium carbonate) and a few experiments were conducted with Fuller's earth.

All the substances tried in our experiments may be found sometimes under natural conditions in suspension in inshore waters. Silt, which is a mixture of organic and inorganic substances, is, of course, very common and is always present in varying quantities. Dredging, or heavy rains which increase river discharge, usually increase the quantities of suspended silt. Clay-like substances, such as kaolin, are also of wide occurrence, sometimes forming a definite stratum under the oyster beds or are encountered in various mixtures with sand. Large quantities of clay are also brought down by the rivers. Chalk, or calcium carbonate, may sometimes be found in the regions of the oyster beds. The shells of the oysters, as everyone knows, are made mostly of this material. Fuller's earth consists largely of shells of small water plants called diatoms.

In our first series of experiments the water was made turbid by the addition of different quantities of silt. We noticed that even when such small quantities as 0.1 gram per liter were added the behavior of the oysters was noticeably affected (Table 1). Usually the type of their shell movement changed and the rate of flow considerably decreased. In the most severe case such a decrease, as compared with the rate of pumping before the oyster was exposed to turbid water, was 87 percent. For the group as a whole, however, the reduction in the rate of pumping averaged 57 percent. In other words, when turbidity was such that there was one part of silt in 10,000 parts of sea water the average pumping rate of the oysters was less than half of that recorded under normal conditions.

Concentrations of 0.25, 0.5, 1.0, 2.0 and 4.0 grams of silt per liter of sea water were later tried using a large number of oysters. The results showed that in all groups there was a sharp decrease in the pumping rate (Table 1). When the concentration of silt in sea water was 1.0 gram per liter or more the average rate of pumping decreased more than 80 percent reaching approximately 94 percent in very heavy concentrations of 3 or 4 grams per liter. Although such heavy concentrations seldom occur, they may, nevertheless, arise during heavy floods or be created and maintained for long periods within the areas where intensive dredging operations are in progress, especially if the dredging methods used are of such type that they will allow large quantities of mud to escape overboard.

As a rule, the experimental oysters were filtering off large quantities of silt. Nevertheless, particles of silt passed through the gills and some was found in the stomachs and intestines of the oysters. In other words, our observations showed that although their efficiency of feeding was greatly depressed, the oysters could ingest small quantities of solid particles even while surrounded by very turbid water. Some oysters, however, stopped feeding entirely although their shells remained open and moving.

The shell movements of the oysters were markedly affected by the addition of silt to the water. This was especially well demonstrated in stronger concentrations. Usually the shell movements became of greater amplitude and their character was of a different type than that observed in the same oysters under normal conditions. This type of shell movement was associated with ejection at frequent intervals of large quantities of silt which was accumulating on the gills of the oysters. This type of shell movement closely resembled that observed in our experiments where the oysters were exposed to large quantities of microorganisms, such as Chlorella, Nitzschia or commercial yeast. In general, the results of the two studies showed a definite similarity in the behavior of oysters in turbid waters regardless of whether this turbidity was caused by a large number of microorganisms or just silt.

In almost all instances when the flow of silt-laden water was substituted with regular sea water the oysters quickly recovered. The character of their shell movement soon changed to normal and the pumping increased to the normal rate or even exceeded it. This cleansing reaction was also noted in our experiments on the feeding of oysters and was usually associated with the change from water too rich in food forms to normal conditions.

In the next group of experiments turbidity was created by adding to the water different quantities of kaolin ranging from 0.1 to 4.0 grams per liter. The results of these experiments were very similar to those obtained when silt was used. Again we found that the addition of even such small quantities of kaolin as 0.1 gram per liter noticeably decreased the pumping rate of the oysters

(Table 1) and changed the character of their shell movement. As the concentrations were increased, these reactions became more and more prominent. At high concentrations, such as 2.0 or 4.0 grams of kaolin per liter of sea water, the shell reaction was especially vigorous showing that the oysters were cleaning their gills from foreign particles. Nevertheless, even in high concentrations the majority of the oysters kept their shells open most of the time and pumped some water. However, judging by the reduction of the rate of pumping and changes in the shell movements, it was evident that the oysters were under unfavorable conditions.

Again, as in previous experiments, the oysters upon return to regular sea water quickly resumed a normal or even more than normal rate of pumping as if to cleanse their gills. Their shells also soon began to move normally.

Experiments with chalk (calcium carbonate) fully corroborated the conclusions obtained in the two previous series, namely, that the presence of turbidity-creating substances in the water greatly reduced the rate of pumping, and therefore feeding, of oysters and affected the character of their shell movements. The latter was especially evident. The experiments with Fuller's earth were conducted only with a small number of oysters and only one concentration of 0.5 gram per liter was used (Table 1).

In our experiments the oysters were kept in turbid water for comparatively short periods rarely exceeding six hours. Therefore, we cannot say definitely what would have happened to the oysters if the experiments had been carried on longer. Nevertheless, on the basis of our observations we may safely conclude that oysters are very sensitive to the presence in the water of turbidity-creating substances, such as silt, clay or chalk. When the concentrations of these substances are increased the quantity of water pumped by the oysters through their gills is sharply decreased. Our data also indicate that there may be a correlation between the increase in turbidity and the decrease in the rate of pumping. In strong concentrations oysters may cease pumping entirely. Therefore, we should always consider with suspicion and caution any condition where the turbidity of the sea water is raised considerably above its normal level, be it because of a heavy river discharge or because of man's activities, such as dredging, well drilling or similar operations.

In conclusion I would like to emphasize that our studies were made only with Long Island Sound oysters which are accustomed to living in comparatively clear water. We know, however, that in other parts of the country oysters live and propagate in very turbid water. At this time I am not prepared to offer an explanation for this phenomenon, but it may be possible that we are dealing with different races of oysters. It is my opinion, nevertheless, that we cannot discuss intelligently the effects of turbidity upon the behavior of oysters unless we have in our possession certain facts based upon extensive experimental observations. Therefore, I feel that our studies of the effect of turbidity

on the rate of water pumping by the oysters of Long Island Sound are a necessary step in our understanding of oyster behavior and I hope that similar studies will soon be conducted in other geographical sections of the country where oysters live under different ecological conditions.

TABLE 1. Percent reduction in pumping rate of oysters subjected to different concentrations of turbidity-creating substances. Rate of pumping in sea water at the beginning of the experiments was taken as 100 percent.

| SUBSTANCE USED | CONCENTRATION gr/lit | AVERAGE REDUCTION IN RATE OF PUMPING IN % |
|---|---|---|
| SILT | 0.1 | 57.0 |
| " | 0.25 | 74.5 |
| " | 0.5 | 68.5 |
| " | 1.0 | 81.0 |
| " | 2.0 | 85.0 |
| " | 3.0 | 93.7 |
| " | 4.0 | 94.0 |
| KAOLIN | 0.1 | 46.0 |
| " | 0.25 | 68.0 |
| " | 0.5 | 68.5 |
| " | 1.0 | 71.0 |
| " | 2.0 | 78.0 |
| " | 4.0 | 85.0 |
| $CaCO_3$ | 0.1 | 38.0 |
| " | 0.5 | 76.0 |
| " | 2.0 | 87.0 |
| " | 4.0 | 89.0 |
| FULLER'S EARTH | 0.5 | 60.0 |

# ON POSSIBLE PHYSIOLOGICAL SPECIES IN THE OYSTER, <u>OSTREA VIRGINICA</u>

Dr. Leslie A. Stauber

Department of Zoology, Rutgers University

It should be clearly understood at the beginning of this report that my role is a minor one, that the actual data to be discussed are mostly the results of the long term efforts of others who have generously made available to me for study even unpublished material. That physiological species of <u>Ostrea virginica</u> might exist was first suggested to me about 17 years ago by Dr. Thurlow C. Nelson. I believe the data to be presented here resolve some of the difficulties which, at first, seemed inconsistent with such a view. Though the data are largely the findings of others the responsibility for the interpretations is clearly mine.

It is important to note, that, prior to 1931, for both the waters of Prince Edward Island, Canada and of various parts of the United States various authors stated 20°C. to be the water temperature at which spawning was initiated in the Eastern oyster, <u>O. virginica</u>, under field conditions. The most extensive data are for the waters of Barnegat Bay where observations were made by Dr. Julius Nelson and Dr. T. C. Nelson for almost 50 consecutive years. For over a decade these observations included water temperatures automatically recorded by a continuously recording thermograph. From this body of data the essential relationships between water temperature and the spawning of oysters on the oyster beds were firmly established and have been amply confirmed. These relationships may be stated simply as follows: On an oyster bed with the gradual rise of water temperatures in the spring of the year oysters begin to feed, grow and become sexually ripe but there is a minimum temperature requirement for the initiation of the act of spawning. Not all oysters spawn when this level is reached and some will spawn experimentally at lower temperatures and under other special laboratory conditions. There may even be some oysters which naturally deviate from this minimum level especially under unusually rapid temperature rises but the year after year picture for a carefully studied body of water is essentially the same - no spawning until the minimum temperature is reached and then mass spawning of a significant proportion of the oysters on the bed. Subsequent spawnings may occur at higher than the minimal temperature but in the autumn again after temperatures fall below the observed minimum no further spawning is noted.

The kinds of data used to draw such conclusions are gathered by observing the meats of the oysters themselves either in the gross or in section, by examination of water samples for the distinctive larval stages of the oyster with their known cycle of development or by the collection of recently attached young oysters set on clean shells regularly exposed, removed and examined. All methods give significant data but, for any one area, one or more of the methods may be easier to

apply especially when dealing with large bodies of water and widely scattered areas of oyster bottom.

The first published evidence that not all oysters in the geographical range of O. virginica spawn at a minimum level of 20°C. is that of Hopkins in 1931. Reporting for Galveston Bay, Texas he found that spawning did not start until 25°C. was reached and that when 20°C. was reached the oysters were just beginning to develop mature eggs and sperms. Loosanoff (1932) reported similar findings for the James River. The next deviation reported was that of Loosanoff and Engle in 1940 who claim a minimum spawning temperature of 16.4°C. for Long Island Sound. It should be noted, however, that an unpublished deviation had been observed elsewhere. When Dr. T. C. Nelson shifted the scene of his activity from Barnegat Bay to Delaware Bay, N. J., in the late twenties he soon learned that spawning phenomena were not the same in these two locations. Indeed, on several occasions he noted that spawning and setting might occur in Barnegat Bay before spawning had begun in Delaware Bay although the latter was farther south and warmed up at least equally as rapidly. Subsequently the findings of Dr. Nelson, Mr. J. Richards Nelson and myself over the following decade and a half amply support, I believe, the contention that mass spawning of oysters over the larger beds of oysters in Delaware Bay does not occur until water temperatures reach 25°C. (I think we must exclude the very shallow inshore areas from consideration because of the greater amplitude of the temperature fluctuations noted in them.)

It might then be stated that three types of oysters exist on the Atlantic seaboard each of which shows a different minimum spawning temperature. The great problem in accepting this viewpoint was the apparent difficulty of reconciling the 20°C. minimum spawning temperature of the oysters of Eastern Canada with that of a lower minimum spawning temperature for Long Island Sound, geographically some 600 miles airline northeast of Long Island Sound. The year 1937 presented the opportunity for resolving this problem. Figure 1 is a graph on which are plotted the published data of Loosanoff and Engle for bottom water temperatures at three stations in Long Island Sound off Stratford Point in 10, 30 and 60 feet of water during the summer of 1937. Also plotted are the published findings of Medcof for the same year (1937) for the waters of Bideford River, Prince Edward Island, Canada and our own unpublished records for several scattered stations in the New Jersey waters of Delaware Bay. It is immediately evident from this figure that practically no overlapping of temperatures occurs in the three areas and that they fall in the sequence of the minimal spawning temperatures of 25°, 20° and 16.4°C. reported, with the Bideford River falling between those of the other two though geographically so much farther north. It might be claimed, however, since all three areas do reach 20°C. at some time in the summer, that the same 20°C. temperature could conceivably initiate spawning in each area. For Delaware Bay the water temperature was maintained above 20°C. after May 24, 1937, in Bideford River after June 25 but in Long Island Sound not until after July 12 or a

spread of 48 days for the three areas. The times given by the observers for the first general spawning in the areas mentioned, however, (excluding minor spawnings of inshore areas) are July 7-8 for Delaware Bay, June 26-30 for Bideford River and July 3 for Long Island Sound, a spread of only 12 days for such widely separated areas. To me this seems more than coincidence. I regard these observations as a very likely indication of the presence of three physiological varieties of oysters with different minimum spawning temperatures, most probably the 25°, 20° and 16.4°C. values already mentioned.

Let us look at the problem in another way. Figure 2 represents the annual cycle of water temperatures for Delaware Bay where the 25°C. minimum spawning temperature occurs. We see approximately a six-week period with temperatures above the minimum spawning level. At the other extreme we see a period of about 15 weeks with temperatures below 5°C. This 5°C. temperature according to the work of Galtsoff, Nelson and others, represents the point at which ciliary activity of the gill, shell movements and heart beat cease in the oyster. It is a point limiting the activity of the oyster. Actually in Delaware Bay no food is found in the oyster stomach until approximately 10°C. is reached. There remains then a period of 11-12 weeks in the spring for growth and maturation of sex products and a similar period in the autumn for growth and storage of food reserve for the so-called winter "hibernation" period.

For Barnegat Bay in 1933 there were 18 weeks above the minimum spawning level of 20°C. and 9 weeks each in spring and autumn between 5° and 20°C. If these intervals represent a favorable balance between periods for growth and for reproduction in the oyster on the natural oyster beds and if the 20°C. spawning level were the limiting factor throughout the range of the species O. virginica then oysters in Long Island Sound and Texas might not have persisted in their respective localities; in the latter case because of reproductive over-activity (33 weeks above 20°C.) and in the former case because of prolonged hibernation or reduced opportunities for spawning (9 weeks above 20°C.). Many investigators already believe that the explanation for the great masses of oyster shells in the kitchen middens of Maine can best be explained in such a fashion by the failure of favorable spawning conditions to occur probably due to a combination of climatic conditions plus the depredations of man.

Table 1 illustrates this point in another way showing the water temperatures observed in several geographical areas. Actually, Delaware Bay seems to be the borderline between more northerly areas with brief or no periods of water temperatures above 25°C. and more southerly areas with few or no consistent temperatures below 5°C. Obviously, conditions along the sea coast from Long Island Sound to Texas are so different that the assumption of biological varieties of the oyster would make more reasonable the observed distribution of the oyster since it would make possible combinations of periods of growth and reproduction more consistent with the survival of the species. However, it must be noted that for any given species there are extremes beyond which no further such combinations are possible. One of these for the oyster is the cessation of ciliary

activity. Thus the total number of such combinations is limited. In the case of the oyster the evidence presented here today seems to indicate three varieties.

Furthermore, as Setchell, and Nelson and Crozier have pointed out, there are certain critical temperatures in the activities of living organisms associated with the initiation of vital processes and that these points do not form a continuous intergraded series but a discontinuous one with the critical points most frequently at 4.5°, 9°, 15°, 20°, 25°, 27° and 30°C. Thus, the number of possible varieties may be limited to the three which now seem existent.

There is no doubt that much more data needs to be accumulated before a more accurate picture can be presented but the broad indications seem already to have been outlined. Similar evidence is available that the oyster drill, Urosalpinx cinerea, is represented by three ovipositing varieties in Narragansett Bay, Delaware Bay and Hampton Roads. In fact the data for the oyster drill are in some respects even better than for the oyster. Here the response of egg-laying is an individual one rather than the mass spawning reaction of the oyster and lends itself to easy observation in the laboratory or in experimental cages in the natural habitat. The three biological varieties oviposit at 10°, 15° and 20°C.

Geographical isolation is recognized by biologists as an important factor in the origin of new species. For the thousands of years before the white man began to shift oysters from bay to bay on our seaboard, the degree of isolation of the oysters of Delaware, Barnegat and Chesapeake Bays and Long Island Sound was practically complete. The oyster, as we know it, is not an ocean but an estuarine dweller so it is extremely difficult to conceive that interbreeding at the margins of the group areas could have occurred in recent time. Assuming that mutation occurs in oysters as in other forms of life the existing geographical isolation and the time available would have been favorable for the action of natural selection and the production of biological species of the oyster.

Although there is no supporting evidence available I believe other organisms along our seaboard will prove divisible into similar races. For example, judging by the range of Venus mercenaria and the hydrographical conditions reported I seriously question Belding's report of spawning in Massachusetts at a minimum value of 24-25°C. though I feel certain that Nelson's value of 25°C. for Delaware Bay is well substantiated.

Whether these are true species in the usual sense of the word can only be determined by experimentation. It should be recalled, however, that interbreeding can be prevented by lack of coincidence of sexual maturity as well as by other kinds of isolation.

If these physiological varieties are as real as they seem to be there are a number of practical implications for the oyster industry.

Suppose, for example, oysters from Chesapeake Bay with a probable minimum spawning temperature of 25°C. are introduced into Long Island Sound for spawning purposes. This temperature rarely if ever is reached in most portions of Long Island Sound. How then can interbreeding or even spawning occur as a result of this procedure? Loosanoff and Engle have shown that the minimum temperature for spawning of the Long Island Sound oyster is 16.4°C. If transplanted to Chesapeake Bay they would probably begin spawning in late April or two months before the local oysters would spawn. Most likely the introduced Sound oysters would be spawned out before the local ones began. No interbreeding is likely if such a difference in spawning dates occurs.

It is evident that many more observations are necessary to test the hypothesis proposed but before that evidence is available I believe we can draw one conclusion concerning the rehabilitation of oyster beds in any given area. Until the biologist can breed in the laboratory a new and better variety of oysters the oystermen would do well to specialize with the oysters of his local area and take advantage of the selective processes of nature which for thousands of years have produced oysters especially fitted for survival in that given locality.

TABLE 1. Water Temperatures - Eastern and Southern North America.

| LOCALITY & | WEEKS OF DURATION | | | | |
|---|---|---|---|---|---|
| REFERENCE | Above 25°C | Above 20°C | Above 10°C | Below 10°C | Below 5°C |
| George's Bank (Riley) | 0 | 0 | 22 | 30 | 19 |
| | Highest cruise mean 16.5 | | | | |
| Prince Edward Is. (Medcof) | 0 | 6-8 | Ice-Nov. to May | | At least 28 |
| Long Island Sd. (Loosanoff)(Riley) | 0 | 8-9 | 27-28 | 24-25 | 13 |
| Barnegat Bay (Nelson) | 3 (not continuous) | 15-18 | 29 | 23 | 14 |
| Delaware Bay (Stauber) | 6 | 17 | 31 | 21 | 15 |
| Solomon's, Md. (Newcombe) | 1-4 ? | 17 | 33 | 19 | 4 |
| Virginia (Federighi)(Galtsoff) | 9 | 22-24 | 35-41 | 11-17 | 1-9 |
| Beaufort, S. C. (Smith) | 19-21 | 29 | 52 | 8-11 | 0 |
| Apalachicola, Fla. (Pearse)(Smith) | 19-21 | 29 | 52 | 0 (?) | 0 |
| Louisiana (Kavanagh)(Owen) | 18 | 28.5 | 52 | 0 | 0 |
| Texas (Moore)(Hopkins) | 27 | 33 | 46 | 6 | 0 |

EFFECTS OF POLLUTION AT BALTIMORE ON pH AND OXYGEN CONTENT OF WATER

Fred W. Sieling

Biologist, Maryland Department of Research and Education

Since the end of the war, interest has been revived in water pollution control. As a result of this and the fact that the offending parties can not now stand behind the Services and declare their inviolability, it was felt that an investigation of present conditions was timely. A public consciousness of the pollution problem is forcing the local conservation agencies as well as federal to take steps toward rather stiff control methods. Maryland, during the late legislature, set up a Commission on Pollution Control with an executive secretary and money to enforce its regulation. The Department of Research and Education of Maryland was designated as their research agency.

Baltimore Harbor, the second largest port in the East, is Maryland's greatest pollution problem. As this Department had conducted rather extensive investigations there before the war and during the early part of the hostilities, we felt that we should resume our investigations, which were halted by lack of man power. Through the Baltimore City Harbor Board which has provided boats for our use, we resumed sampling trips in February 1946. These trips are made at bi-weekly intervals, depending on suitable weather conditions, to eleven stations selected as being representative of general conditions in the several areas of the Harbor. These also form a pollution gradient.

The water at these stations is being analyzed to determine the following conditions: the temperature; the pH or potential hydrogen, which gives an index of the relative alkalinity or acidity of the water; the oxygen content, the variations of which is indicative of pollution as well as denoting whether animal life could exist in the water; the salinity, which is useful to know in connection with the other analyses; and the ferrous and ferric iron content.

The temperature is taken with a calibrated reversing thermometer which is attached to a Nansen-Knudsen water sampler with which the water samples are taken. The pH is determined by using a Beckman pH meter with a flow electrode. The oxygen is determined by the modified Winkler method. The salinity is determined by titration with silver nitrate. A rough qualitative detection method is used in the field to determine the ferrous iron content. The ferric iron samples are treated and analyzed at the laboratory with an electrophotometer.

Large natural oyster bars lie across the entrance to Baltimore harbor and were once great producing areas, which now are nearly barren. This condition, it is contended by some, was caused by pollution. Last year at this meeting, Messrs. Engle and Beaven

reported on the high oyster mortality on the upper Bay bars. Their conclusion was that fresh water had killed the oysters.

Industrial and municipal wastes are both large factors in the pollution of Baltimore harbor. The industrial effluent is principally iron sulphate of which a large amount comes from copperas. The polluting chemical in this is $FeSO_4.7H_2O$. This, when dumped into the Harbor, hydrolyzes to form sulfuric acid and ferrous hydroxide. The pollutant comes from the steel mills and from the different pigment and paint manufacturers. Other large sources of industrial pollution are the industrial alcohol plants, which throw mash into the water, and the fertilizer plants which dump quantities of spent sulfuric acid into the Harbor. Of course there are many small contributors such as canneries and small chemical manufacturers whose cumulative effect is undoubtedly felt.

Municipal wastes have increased greatly since 1940 when the population of the City was greatly boosted by the influx of war workers. Up to that time the City had managed to treat most of the sewage, but from then on and continuing to the present time, nearly half of the sewage of Baltimore City is dumped untreated into the Harbor. The depressing effect of this on the oxygen content is felt over a large area.

These effects were first studied by Olson, Brust, and Tressler in 1939-1941 and later by Stern and Davis in 1942. Several exploratory trips were made by the author in 1938 but no data were published as it was fragmentary.

At the earlier date conditions were bad at several areas but it was decided that further studies should be made before any conclusions could be drawn. Olson, et al., started their comprehensive study in 1939 and their data show a high degree of pollution over a wide area. Later, after the start of the war, Stern conducted a study over the same area with some additional stations being observed. At this time the degree of pollution was less than it had been. However, at the present time, the degree of pollution is greater than during any previous investigation. These changing conditions were brought about in the following manner.

Before the war industry and shipping were at a normal level and Baltimore City was treating most of the sewage. After the start of the war industry was converting and not dumping as much waste because their production was down from a prewar level. The sewage had not appreciably increased and shipping was somewhat below normal. The steel mills were producing ingots and large plates which use very little pickling liquor, rather than sheet metal which uses a great volume of acid. The pigment companies could not obtain raw materials so their waste was far less than previously . Other manufacturers were affected in a similar manner so that there was less pollution from industry during the war. However, larger volumes of sewage were being dumped in the Harbor during this period. Since the end of the

war, because industry is now producing far above the prewar level, pollution has greatly increased. Industry has again reconverted to peace time products which, as stated before, give large volumes of copperas which is discharged into the Harbor. Small concerns, as well as the large manufacturers contribute to this condition. Sewage also is at a high level.

The enormous volume of copperas discharged into the water has the following effect. The ferrous sulfate or copperas hydrolyzes readily in water solution, lowering the pH and forming the corresponding base. The rate of hydrolysis decreases with acid concentration and the rate of oxidation of ferrous hydroxide depends on the concentration of oxygen in the water. Both the formation of sulfuric acid and the use of oxygen for the conversion of ferrous hydroxide to ferric hydroxide are harmful to marine organisms. The first, because it lowers the pH to a point which is lethal to marine life and the second, because it lowers the oxygen tension below the safe limit for life of marine organisms. The iron in the water is not in itself in sufficient quantities to be lethal, but its effect on the pH and oxygen is very harmful.

Sewage in the water decreases the oxygen content but does not greatly depress the pH. The effect is very local and further away from the source may even be beneficial to aquatic life, though not conducive to human health.

The approximate lower limit of tolerance of marine organisms to pH is 4.5 and for oxygen is 3.5 cc/l. according to Ellis, 1937. It will be seen that these lower limits were violated many times at most of the stations.

The depth of water at the different stations ranges from 10 to 30 feet; tidal variations are not great, being from 12 to 25 inches. The current velocity is variable, ranging from zero to 0.2 knots per hour (Haight, 1930). Winds affect the Harbor waters even more than tides. Stations were selected as being representative of the different areas as much as possible and also to make a pollution gradient. The station farthest out is just 200 yards from an oyster bed. This is at Seven Foot Knoll which is about 5 miles from the nearest source of pollution.

Discussion of Results of Different Stations:

Station I is located on Colgate Creek which is about 10 feet deep where one of the larger plants is dumping waste. The pollution here is mainly copperas or ferrous hydroxide which, as was explained, lowers the oxygen and pH to a very dangerous point. The average surface oxygen concentration during the sixteen month period was 0.72 cc/l. and the average pH was 3.3. The concentration of oxygen at the bottom averaged 0.51 cc/l. and the pH there was 3.1. This is the worst station in the group as the readings were consistently below the lower limit for life to exist.

Station 2 is located at the mouth of Colgate creek where the depth is 16 feet and some mixing with other water has taken place. Here the oxygen concentration has risen to 4.0 cc/l. at the surface while the bottom is 3.3 cc/l. average. The pH is also higher being 6.2 at the surface and 6.4 at the bottom. However, at these two stations it must be remembered that for long periods the oxygen and pH are both below the accepted minimum for maintaining aquatic life.

Station 3 is located near the mouth of Bear Creek which is one of the dumping areas for a large steel plant. Here, a great volume of spent sulphuric acid is dumped which has been used in pickling sheet metal and carries a large amount of ferrous and ferric sulphate. This acid depresses the oxygen and pH levels for long periods of time although the average is not at a point too dangerously low. The volume of water where this is dumped is large being nearly 20 feet deep and a half mile wide. The average oxygen is 4.2 and 3.4 cc/l. at top and bottom respectively, and the pH is 6.1 and 6.3. This station is about 5 miles from the nearest oyster bars.

Station 10 is located farthest from the Bay, being 15 miles from the nearest oyster bars. This is in the Patapsco River proper and the depth is about 30 feet. It is located a mile from a very large sewer outlet of the municipal sewerage system. Here the effects of raw sewage is noted by the low oxygen which is 3.8 and 2.2 cc/l. at top and bottom respectively. The pH is not affected as much, being 6.7 at both top and bottom.

Stations 9, 8 and 7 may be considered in sequence as they are all in Curtis Bay, ranging from the upper part to the mouth. Station 9 which is slightly above the main sources of pollution had an average surface oxygen of 4.0 and an average bottom oxygen of 1.1 cc/l. The pH was 4.7 and 5.2 for top and bottom respectively. Station 8, which is very close to the sources of pollution, approximately .4 mile, had an average surface oxygen reading of 3.9 cc/l. and an average bottom reading of 1.3 cc/l. The pH was 5.4 and 5.5 for top and bottom. Station 7, at the mouth of Curtis Bay, about 2 miles from the source of pollution, showed less pronounced effects. The average surface oxygen was 4.2 cc/l. and on the bottom it was 2.0 cc/l. while the pH averaged 6.3 at both top and bottom.

Stations 4, 5, 6, and 11 are in a direct line toward the Bay and form a gradient from the polluted area to the water of the Bay. Station 4 is off Sparrows Point, where one of the largest sources of pollution is located. The oxygen at the surface was 5.1 cc/l. and the bottom was 2.7 cc/l. The pH was 6.9 and 6.8 for top and bottom respectively. Station 5 is further toward the Bay just off North Point. The pH is 7.4 and 7.0 for top and bottom and the oxygen is 5.3 cc/l. and 3.1 cc/l, for top and bottom respectively. Station 6 is at the mouth of the Harbor and presumably affected by the Bay water to a considerable extent. The oxygen averaged 5.6 cc/l. at the surface and 3.0 cc/l. at the bottom. The pH was 7.5 and 6.9 at the top and bottom respectively. Station 11 is in the Bay just outside the Harbor and adjacent to several oyster bars. The average oxygen was 5.0 cc/l. at the surface and 2.9 cc/l. at the bottom while the pH was 7.5 and 7.1 for surface and bottom respectively.

These figures show the decreasing affect of the pollution as you go farther away from the source. Stern, 1942, noted no effect past Sparrows Point (Station 4) but here can be seen the depressing effect much farther out toward the Bay.

## Conclusions

From results obtained in these analyses it is felt that sufficient samples were taken over a period long enough for the result to be considered as average for the several areas. The very worst conditions are local for the several areas, i. e., Colgate Creek, Bear Creek and Curtis Bay, but the effect of the pollution is felt to a lesser extent over a very wide area. When, for instance, one plant in Curtis Bay is dumping an average of 300,000 pounds of copperas per day alone and one steel plant on Bear Creek is dumping 38 million pounds of copperas annually, these pollutants are bound to make their influence felt more than just locally as this material is carried by current, tides and wind action. Other plants for which we have no records of dumping are certainly in the aggregate, dumping as much as the two previously cited. The sewage cannot be estimated, but is in tremendous volume, about half the sewage from a city of a million people.

Comparison of these data with that obtained by Olsen in 1938 and by Stern in 1942, shows beyond a doubt that conditions are far worse now than they were then and that the area of lowered pH and oxygen is larger.

The effects of pollutants extend with decreasing damage into the Bay where our natural resources - oysters, fish and crabs, are still caught in commercial numbers.

Present conditions do not indicate damage to our oyster bars, but continued increase in pollution might seriously affect them. These oyster bars are at present in a very depleted state but can be brought back into production if the condition of the water is such as to support marine life. It is felt, however, that unless something is done to curb this practice of dumping waste, it will be a very serious threat to our upper Bay natural resources. It is hoped that something will soon be done to at least halt the further spread of this blighted area. There is, however, a strong sentiment among some people that the economic value of the Harbor offsets the value of the natural resources in this area. We feel that a balance between the two is important. Industry can exist along with pure water and proper disposal methods would permit both industry and natural resources to prosper. This has already been proved in many places. Effective research and understanding of the kind and extent of pollution is essential to real protection of our natural resources.

ADDRESSES DELIVERED

AT THE CONVENTION OF

NATIONAL SHELLFISHERIES ASSOCIATION

Asbury Park, New Jersey

June 2-3-4, 1948.

Dr. Victor L. Loosanoff,
President.

Dr. J. Nelson Gowanloch,
Vice-President.

James B. Engle,
Secretary.

J. Richards Nelson,
Treasurer.

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ADDRESS OF WELCOME

Dr. V. L. Loosanoff

President, National Shellfisheries Association

We welcome this opportunity to meet for an exchange of information and ideas, and for formulating plans for the future. As President of the Association, I welcome all our guests and members. May I say frankly that we are glad so many of you have come to this meeting.

This meeting coincides with the beginning of a new period in the existence of our organization and perhaps with a new era in shellfisheries. I think so because of the following reasons:

1 - Until recently research in shellfisheries was almost exclusively carried on by a small group of biologists of the U. S. Fish and Wildlife Service and biologists of several states, mostly of the Middle Atlantic region. During the last few years the situation has changed radically.

a - First, several new states have realized that the only intelligent and practical way to develop a fisheries and maintain it on a productive basis is by getting and properly applying a knowledge of the biology of commercial species. As a result, several more aquatic biologists have been engaged by the states, and some of these states are either building or planning to build laboratories where the work will be centered.

b - Second, several industrial companies of the Gulf of Mexico, which at first glance have no relation whatsoever to shellfisheries, have established large centers of research by hiring a number of biologists who will, no doubt, make significant contributions to our knowledge.

c - Finally, many large private oyster companies have come to the conclusion that it may be of definite advantage to include a biologist on their staff. Several of these men were sent by their companies to be trained in certain aspects of marine biology at our laboratory at Milford. We are glad to see some of our graduates attending this convention.

Thus, many more men are now working on the biology of shellfish.

2 - The second reason that makes me assume that we are entering into a new period is that the oyster has ceased to be the only shellfish to which almost the entire research has been confined. Those of you who are familiar with the literature on shellfisheries will remember that since the days of Belding, which is roughly 40 years ago, practically no research on clams has been done on the Atlantic coast. The exceptions are Newcomb's papers on the growth of clams, my articles on the hard-shell

clam, and a few others. In other words, these fisheries have received very little attention from scientists. Recently this situation has also changed. In New Jersey a comparatively large group of scientists, under the general direction of Dr. Nelson, is working on the life history and methods of propagation of the hard clam, Venus mercenaria. In Canada a great deal of work has already been accomplished on the soft clam, Mya arenaria, by Dr. Medcof and his co-workers. The State of Maine has a biologist working on the soft clam, and in Massachusetts, the Woods Hole Oceanographic Institution has undertaken clam studies. Perhaps soon the Fish and Wildlife Service will participate in the clam studies.

3 - The third consideration is also an important one. My contacts and conversations with the more experienced men of our group have led me to the conclusion that most of us are beginning to understand the necessity of concentrating on the basic studies of the physiological requirements of oysters and on their relation to the environment. We must confess that we still do not know what steps should be taken to produce fat oysters - which is the chief purpose of every oyster grower. It is imperative, therefore, to concentrate on studies of the nutrition of oysters.

Equally important are studies that will give us a better understanding of the conditions controlling the existence of oyster larvae. We must know what factors are responsible for the failure of oyster larvae to reach the setting stage. For this we must learn what constitutes the food of larvae, what marine forms are larvae enemies, what effects have different factors, such as temperature, salinity, etc. All these things are still virtually unknown to us. However, failure of larvae to survive to the setting stage results in heavy financial losses to the oyster growers who plant hundreds of thousands of bushels of shells in the hope of getting oyster set.

4 - Finally, this is the beginning of the period when the shellfishery industries have decided to break away from the old methods of cultivation and harvesting. In Long Island Sound modern suction dredges are definitely displacing the old type oyster boats. I was fortunate to see some of these in operation and am impressed with their efficiency and versatility. In the Gulf of Mexico a clam-harvesting device has been perfected and will probably be accepted with minor modifications in other parts of the country. Many of these innovations will be described by the speakers appearing on our program.

In conclusion, I wish to extend once more a sincere welcome to our guests and the members of the three organizations meeting here. Let's try to make this meeting a successful one!

LATE SUMMER AND EARLY FALL SPAWNING OF OYSTERS AND ITS RELATION TO SETS OF COMMERCIAL VALUE

A. F. Chestnut,

New Jersey Oyster Research Laboratory, Rutgers University [1]

Practical oystermen from many of our oyster producing areas along the Atlantic seaboard will often tell you that spawning and setting of oysters takes place throughout the winter months. For evidence to support their contention the oystermen will show you very small spat, a quarter of an inch and less in diameter which have been dredged during the early spring months. The explanation that has been offered for the occurrence of these small spat is that a set occurred late in the fall and with the decline in water temperatures the rate of growth of the spat becomes very slow or ceases entirely. This appears to be a suitable explanation. However, there are some interesting facts that may have a bearing on this matter.

In Delaware Bay occasional straight hinge larvae have been found late in November with water temperatures as low as 5° or 6° centigrade. In some cases it is not certain these were oyster larvae, for it is difficult at times to distinguish the various bivalve larvae in their earliest stages. Loosanoff (1939) recorded finding a female oyster in a partially spawned condition on March 20 and a male oyster with ripe and active sperm about the same time in Long Island Sound with the water temperatures near 0° centigrade. There may be some doubt whether such oysters were spawning, yet A. E. Hopkins reported that the Pacific oyster (O. gigas) will spawn at temperatures as low as about 8° centigrade. These oysters normally spawn at temperatures above 20° centigrade. In recent years a good deal of evidence has been presented showing that temperatures alone may not be the all important factor involved in stimulating spawning. Individual variations among oysters are well known from physiological studies and such cases of possible winter spawning, if it may occur does so but rarely. Such cases are of interest and add to the general knowledge of the oyster.

In the past twenty-five years the many investigators have shown that spawning and setting may generally occur throughout the summer months. A study of these results shows that variations in time of setting may frequently occur. In some years the heaviest set may follow the initial spawning period; in other years, the heaviest set may not take place until a month or two after spawning first began and still in other years there may be two or even three peaks of intense setting during the same season. Briefly, to illustrate these points from the literature, Nelson (1929) showed two periods of intense setting to occur at the Cape Shore,

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[1] now with the University of North Carolina, Institute of Fisheries Research, Morehead City, N. C.

Delaware Bay. The first intense set took place on July 30 and the second between August 13 and 20. The next year (1930) three waves of intense setting took place, the first on July 30 with a count of 367 spat per shell, the second on August 8 with a count of [illegible] spat per shell and the third set on August 20 with a count of 125 spat per shell.

Prytherch (1929) found two spawnings to occur in Long Island Sound, the first about the middle of June and a second spawning about the first of August, resulting in two sets. The first set being extremely light, followed by a heavy final set about the middle of August. Loosanoff and Engle, however, found the heaviest set to occur about July 20 in Long Island Sound with a light set following late in August of 1937.

In the Chesapeake Bay area, Loosanoff (1931) found setting to occur continuously throughout the season in the James River, Virginia with the peak of setting about September 16. Galtsoff et al., (1936) reported two periods of heavy setting from the lower York River, Virginia, the first in the latter half of July and the second about the middle of September. Mackin (1945) records the major strike in seaside Virginia taking place between July 15 and 25.

In following the intensity of setting at various stations in Delaware Bay for the past few years similar variations have been observed as to peaks of setting at the same station and at different stations each year. The intensity of setting was determined in the conventional manner of using test shells in wire baskets changed at approximate five day intervals. The results of setting for the past three years at one area, station 9, Delaware Bay, N. J., are presented in the accompanying figure 1. In 1945 the heaviest set occurred about July 5. Continuous setting was recorded from June 24 to July 30. Then after 20 days of no recorded set of oysters, a light set was found between August 20 and 25. Similar results were obtained in 1946 with the heaviest set about 20 days later than in 1945. Setting in 1946 ceased entirely by August 5 with a light set occurring between August 15 and 20. In 1947 the period of setting was delayed, beginning July 15 and setting continuously until the first of October, with the maximum setting taking place between August 15 and 25.

An interesting observation at the same station 9 in 1944 and in 1947, which may be coincidental, was that the water temperatures averaged 22.5 degrees centigrade when spawning first commenced as well as at the time of spawning prior to the last recorded set. In the first case the water temperatures were rising and in the latter, the temperatures were declining from the higher temperatures of 26 and 27 degrees centigrade in July and August.

In the studies of setting a point of interest is the set which continues to appear late in August or September and may be of commercial importance. In the Chesapeake Bay area and south the late set often proves to be the one of commercial value. It should not be

overlooked in other areas, particularly in those years when the early set is a failure. In such cases it is important to watch the fouling of shells which have been scattered as cultch earlier in the season.

The importance of getting shells overboard at the proper time has been well emphasized in the past. However, sometimes it is not possible to hold shells until the proper time due to circumstances or perhaps as a matter of habit. In Delaware Bay, for example, it is the general practice to scatter shells for cultch before July 4. In some seasons this works out well as in 1945 and 1946 when the peak of setting was in July. In 1947 with the peak of setting coming late in August, the majority of the planted shells had lost their efficiency as spat collectors because of heavy growths of tunicates, bryozoans and hydroids on the shells. A single experimental clam shell, measuring 3 1/2 by 4 inches was completely covered with bryozoa in 15 days. One oysterman on finding his shells in this condition was able to secure a set of importance by dragging the shells and turning them over.

The question may arise, "How can you account for a late set?" or "What is the explanation for a late set?" There are undoubtedly many factors involved and any single answer may be far from complete. The following factors may be among those involved in a late set.

First, our native eastern oysters as a rule do not spawn out completely when spawning is first stimulated. Throughout the summer months we find oysters at various stages, some may be completely spawned out while others are only half or partially spawned out. Nelson (1928) in Barnegat Bay and Loosanoff (1942) in Long Island Sound have shown that there may be great differences in the degree of maturity among oysters from the same bed at the same time. Successive spawnings throughout the summer reaching into the fall may offer one explanation for a late set.

Second, oysters have often been observed going into spawn a second time in the same season. Shucking house operators are well aware of this fact and are not too pleased to find this condition. To cite one instance, oysters which had spawned out in the Mullica River, N. J., when brought to the Cape Shore of Delaware Bay August 1 were found to have gone into spawn a second time by the end of August. Possible spawning of such oysters would produce a late set.

Third, with decreasing water temperatures the pelagic or free swimming period of the oyster may be prolonged. Prytherch (1934) and Medcof (1936-37) have presented evidence to support this factor. Medcof's studies in the Bideford River district have shown that the larval period may extend for as long as 30 days before setting. Thus with oysters spawning during declining water temperatures, the setting may be delayed for a considerable period.

A fourth factor may be that of salinity influencing the larval stages. Prytherch (1934) pointed out that in Long Island Sound with lower salinities the larval periods are shorter and conversely when salinities are

higher than usual the larval period may be prolonged. This factor may well supplement the influence of declining water temperatures in such areas as Delaware Bay where salinities are usually at their maximum in October or November.

In conclusion, the many factors that are apparent in stimulating spawning and influencing the larval period of oysters make it unwise to predict from a long range basis when the greatest intensity of setting may occur before oysters have commenced to spawn.

# THE 1947 OYSTER STRIKE IN THE JAMES RIVER

Dr. Jay D. Andrews

Biologist, Virginia Fisheries Laboratory

Abstract

The 1947 weekly spat strike and seasonal survival of spat were studied on public bars in three widely varying areas of the James River by planting shells in wire bags. The strike was good throughout the river. The number of larvae setting was very high, and despite the low rate of survival, the set was effective. On the best bar, an average of 314 spat per shell set during the season of which 14 were still alive in November 1947. Each bar was characterized by a particular level of setting regardless of the time shells were planted. Setting varied much more from bar to bar than as a result of different times of planting shells on the same bar.

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The setting of oyster larvae in Virginia waters may occur anytime between the first of July and the first of October. The James River seed area usually gets a continuous set throughout this period. In contrast, the setting period in more northern waters is shorter and setting is often limited to one or two broods of larvae. It has become the practice of oyster biologists from several states north of Virginia to study larval broods closely each year. Shell plantings are made just a few days ahead of the expected setting of larvae. This procedure has never been practiced in Virginia. The combination of a long setting period and the presence of many overlapping broods makes recommendations for time of planting shells more difficult.

A number of investigators, including Loosanoff (1932), and Newcombe (1946) and his associates, have observed that the effective sets in the James River have occurred in late August or in September. In 1946, the writer observed an effective strike occurring very late in September and in October. In accord with such observations, some Virginia oyster biologists have recommended late shell plantings -- August or September. Since neither state nor private planters have followed these recommendations for various practical reasons, it behooves us to make further inquiries about the value of late shell plantings in the James River.

This report is an attempt to evaluate the importance of <u>time</u> in shell planting on the basis of the 1947 set. Since data have been collected for only one year, conclusions are tentative.

In order to duplicate as nearly as possible the conditions obtained in commercial plantings, oyster shells in wire bags were placed on the bottoms of representative bars. However, freshly shucked oyster shells

were used and all shells were washed before planting. Three oyster bars were chosen from the public grounds in the James River -- two in the seed area, and one market oyster producing bar (Fig. 1). Shell bags were planted in duplicate at all stations.

Two series of shell bags were planted. In the first series, bags of shells were exposed for successive weekly periods from late May until November to obtain the weekly spatfall. The spat on the inside faces of twenty shells were counted from each of these bags. In the second series, shells planted the first of each month from June to October were left until November for a comparison of the number and size of spat surviving. All spat on one hundred shells from each bag were counted in this series.

The three oyster bars chosen are briefly characterized in Table 1.

Table 1. Characteristics of three oyster bars in the James River.

| | Nansemond Ridge (lower river) | Wreck Shoal (middle river) | Deep Water Shoal (upper river) |
|---|---|---|---|
| 1. | High salinities | Moderate salinities | Low salinities |
| 2. | Intensive fouling (many species) | Moderate fouling | Moderate fouling (few species) |
| 3. | Drills present | Drills absent | Drills absent |
| 4. | No fresh-water kills | Rare, if ever | Fresh-water kills |
| 5. | Light silting | Moderate silting | Heavy silting |
| 6. | Mostly market oysters | Mostly seed oysters | Mostly cinder, few seed oysters |

Conditions vary widely on the three bars chosen for study. The lower bar, Nansemond Ridge, is primarily a market oyster ground. The salinity measures about 20 parts per thousand in mid-summer. Drill predation is heavy and fouling intense. Several species of sponges, as well as Crepidula and jingles, are present. Wreck Shoal, the second station, is in the heart of the seed oyster area. The bottom has mostly seed oysters and very little shell. The salinity approximates an average of 16 p.p.t. in mid-summer. Drills, sponges, Crepidula and jingles are usually absent. Deep Water Shoal, the upper station, is characterized by fresh-water kills -- one of which occurred in the spring of 1948. In May 1948, heavy mortalities were found on this bar, including spat, yearlings, and two-year-old oysters. A large portion of the material on the bottom is cinder (shell fragments). Silting is frequently heavy.

## Weekly spat strike

The weekly spat strike on shells in bags was counted for all three bars. Setting began the week of July 9-16 and was continuous until the first of October. On the typical seed oyster bar, Wreck Shoal, the intensity of setting increased regularly until the last week of August when a peek of 63 spat per shell per week was reached (Table 2).

The peak of setting at the other two stations occurred essentially at the same time with only minor fluctuations. However, fewer spat set at Nansemond Ridge and Deep Water Shoal.

Table 2. Weekly spat strike - James River, 1947 (no. of spat per shell per week)

| Dates set | Nansemond Ridge | Wreck Shoal | Deep Water Shoal |
|---|---|---|---|
| June 27 - July 3 | 0 | 0 | 0 |
| July 3 - July 9 | 0 | 0 | 0 |
| July 9 - July 16 | 0.6 | 4.0 | 0.2 |
| July 16 - July 23 | 1.2 | 2.4 | 0.1 |
| July 23 - July 30 | 1.9 | 10.0 | 0.4 |
| July 30 - Aug. 6 | 2.9 | 15.1 | 3.6 |
| Aug. 6 - Aug. 14 | 19.9 | 28.4 | 1.4 |
| Aug. 14 - Aug. 21 | 33.9 | 56.7 | 1.7 |
| Aug. 21 - Aug. 28 | 5.6 | 62.7 | 7.9 |
| Aug. 28 - Sep. 3 | 20.3 | 60.5 | 8.3 |
| Sep. 3 - Sep. 11 | 14.5 | 43.8 | 5.7 |
| Sep. 11 - Sep. 18 | 10.5 | 18.0 | 0.9 |
| Sep. 18 - Sep. 26 | 1.8 | 8.5 | 1.0 |
| Sep. 26 - Oct. 2 | 0.3 | 3.8 | 0.4 |
| Oct. 2 - Oct. 10 | 0.2 | 0.1 | 0 |
| Oct. 10 - Oct. 24 | 0 | 0 | 0 |

In order to show more clearly the distribution of spatfall by weeks, Table 3 shows each weekly set as a percentage of the total seasonal set. Discounting small variations, each station shows a single peak in late August and early September. The set in the James River has been found in previous years to be progressively later from the lower to the upper river. There is some indication in the 1947 data that the set was about two weeks later on Deep Water Shoal than on Nansemond Ridge.

Table 3. Percentage of total set occurring each week - James River, 1947

| Week of | Nansemond Ridge | Wreck Shoal | Deep Water Shoal |
|---|---|---|---|
| July 10 - July 17 | 0.5 | 1.3 | 0.5 |
| July 17 - July 24 | 1.0 | 0.9 | 0.3 |
| July 24 - July 30 | 1.7 | 3.0 | 1.3 |
| July 30 - Aug. 8 | 2.5 | 4.8 | 11.3 |
| Aug. 8 - Aug. 14 | 17.7 | 9.1 | 4.3 |
| Aug. 14 - Aug. 21 | 29.9 | 18.1 | 5.3 |
| Aug. 21 - Aug. 28 | 4.9 | 19.9 | 25.2 |
| Aug. 28 - Sep. 4 | 17.9 | 19.3 | 26.4 |
| Sep. 4 - Sep. 11 | 12.8 | 13.9 | 18.4 |
| Sep. 11 - Sep. 18 | 9.2 | 5.8 | 2.8 |
| Sep. 18 - Sep. 26 | 1.6 | 2.7 | 3.1 |
| Sep. 26 - Oct. 2 | 0.3 | 1.2 | 1.1 |

A rearrangement of the setting data by adding all the weekly sets gives a seasonal total which I have called potential spatfall. This amounted to 314 spat per shell at Wreck Shoal. From this arrangement of the data, the percentage of set occurring after certain dates can be readily determined, (Table 4). Thus, 95% of the potential spatfall occurred after July 30 and only 5% in July. Likewise, about 25% of the set occurred after the first of September, leaving 70% setting in August. The seasonal distribution of weekly spatfall for the other two stations is almost identical.

Table 4. Potential spatfall - Wreck Shoal, 1947

| Week beginning | Setting days | Per bushel | No. of spat per shell | % of total |
|---|---|---|---|---|
| July 9 | 85 | 188,280 | 313.8 | 100.0 |
| July 16 | 78 | 185,910 | 309.8 | 98.7 |
| July 23 | 71 | 184,370 | 307.3 | 97.8 |
| July 30 | 64 | 178,400 | 297.3 | 94.8 |
| Aug. 6 | 57 | 169,370 | 282.3 | 90.0 |
| Aug. 14 | 49 | 152,300 | 253.8 | 80.9 |
| Aug. 21 | 42 | 118,310 | 197.2 | 62.8 |
| Aug. 28 | 35 | 80,720 | 134.5 | 42.9 |
| Sep. 3 | 29 | 44,450 | 74.1 | 23.6 |
| Sep. 11 | 21 | 18,200 | 30.3 | 9.7 |
| Sep. 18 | 14 | 7,400 | 12.3 | 3.9 |
| Sep. 26 | 6 | 2,300 | 3.8 | 1.2 |
| Oct. 2 | 0 | 0 | 0 | 0 |

## Survival of spat

Information on the survival of spat was obtained from shell bags planted at the beginning of each setting month and left until November. The data show a characteristic level of spat survival for each bar regardless of the time shells were planted (Table 5). Secondly, August planted shells showed a higher survival of spat on all three bars, although the advantage was not great.

Table 5. Average number of oyster spat surviving until November - James River, 1947 (no. of spat per shell)

| Station | Shells planted 1st of: June | July | August | Sept. |
|---|---|---|---|---|
| Nansemond Ridge | 2.58 | 2.42 | 4.45 | 3.70 |
| Wreck Shoal | 13.12 | - | 14.37 | 8.28 |
| Deep Water Shoal | 7.06 | 7.97 | 8.71 | 6.67 |

A study of size relationships showed that spat on shells on Wreck Shoal were consistently smaller but, with less than 15 spat per shell, it does not seem probable that overcrowding could have been the cause

(Table 6). The most unexpected result was that spat on August planted shells averaged larger than those on shells planted earlier. This suggests that fouling interfered with setting on the early planted shells, and that setting was delayed until late summer, perhaps after some fouling organisms had sloughed off in the fall. Some large spat were found on the early planted shells, so retarded growth probably is not an explanation for this reversal of size groups. A more detailed analysis of the size groups shows that there is a single size mode apparently corresponding with the peak of weekly setting found in late August. There were consistently more spat in the larger size groups from the August bags than from those planted in June.

Table 6. Average length of surviving oyster spat in November - James River, 1947 (length in mm.)

| Station | Shells planted 1st of: June | July | August | Sept. |
|---|---|---|---|---|
| Nansemond Ridge | 11.8 | 13.1 | 13.7 | 9.2 |
| Wreck Shoal | 9.6 | - | 11.2 | 6.5 |
| Deep Water Shoal | 12.0 | 12.7 | 14.2 | 9.9 |

A comparison of the number of spat surviving with the total of the weekly strikes--the potential strike--reveals a very low percentage of survival (Table 7). However, the survival of spat setting in September was three or four times greater than for earlier sets. At Deep Water Shoal, the area with the lowest potential set, the percentage of spat surviving was higher than at the other bars, yet, the ratio between the survival of September set spat and earlier ones remained the same at this station.

Table 7. Percentage of spat surviving until November - James River, 1947

| | Shells planted 1st of: | Number of spat per shell Potential set | Surviving set | % Survival |
|---|---|---|---|---|
| Nansemond Ridge | June | 113.2 | 2.6 | 2.3 |
| | July | 113.2 | 2.4 | 2.1 |
| | Aug. | 109.6 | 4.5 | 4.1 |
| | Sept. | 27.1 | 3.7 | 13.7 |
| Wreck Shoal | June | 313.8 | 13.1 | 4.2 |
| | July | 313.8 | - | - |
| | Aug. | 297.3 | 14.4 | 4.8 |
| | Sept. | 74.1 | 8.3 | 11.2 |
| Deep Water Shoal | June | 31.2 | 7.1 | 22.8 |
| | July | 31.2 | 8.0 | 25.6 |
| | Aug. | 30.6 | 8.7 | 28.4 |
| | Sept. | 7.9 | 6.7 | 84.8 |

The only comparable data for the James River on the weekly strike and survival of spat are those collected by Dr. Loosanoff in 1931. The 1947

strike was one of the best in a decade while the 1931 strike was average to poor. In 1947 forty times as many spat settled on the weekly bags as in 1931, but only three times as many survived. It is not thought that overcorwding was a serious factor, for the best surviving set averaged only 15 spat per shell.

## Conclusion

A study of three widely varying bars in the James River indicates characteristic setting rates prevail for each bar and that greater differences occur between bars than result from different times of shell planting on a single bar. No great advantage was found for any particular time of shell-planting. August planted shells showed about a 20% advantage both in size and number of spat over earlier plantings. The enormous magnitude of the potential set suggests that much larger quantities of shell than were present on the seed grounds could have received an adequate set.

The 1947 data imply that planting more cultch at the right place would mean more to the James River seed area than rigid selection of the time of planting.

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# SOME OBSERVATIONS ON THE SPAWNING OF OYSTERS AND REARING OF OYSTER LARVAE THROUGHOUT THE YEAR

Harry C. Davis

Aquatic Biologist, U. S. Fish and Wildlife Service

The immediate goal of the work I am reporting is to develop a standard method of growing oyster larvae to the setting stage, in the laboratory. The final purpose of the investigation is to study the effect, on the growth and survival of larvae, of varying environmental factors, such as temperature, salinity, turbidity, food organisms, enemies, diseases, etc. It is only by determining the effect of these factors in the laboratory, under conditions such that each factor can be varied separately, that we can hope to evaluate their combined effects and predict the survival of larvae and the intensity of setting under natural conditions. This information should be invaluable to the oyster industry.

It is desirable to conduct such studies on a year round basis, not only to expedite final results but also because certain conditions, such as temperature, are more easily controlled during the winter months.

It is convenient to discuss rearing of oyster larvae in the laboratory throughout the year under two headings: first, methods of obtaining spawn throughout the year and second, methods of culturing the resulting larvae.

## I. Methods of obtaining spawn throughout the year

Seasonal gonadal changes of Long Island Sound oysters were described in 1942 by Loosanoff. He found that spring gonad development is resumed in May, soon after the water temperature reaches 10.0°C. Spawning begins late in June or early in July and is usually completed by the middle of September. Thus, if, in his experiments, one had to depend on the spawn produced under natural conditions, his work would be limited to approximately three months. Fortunately, Loosanoff in 1945 offered a method for inducing gonad development in oysters during the winter months. His method consisted in keeping oysters in heated aquaria at temperatures between 20° and 30°C. Korringa reports that Dannevig in Norway successfully applied the method to the European oyster two years later. The same method, with some modifications, was used for obtaining spawn in the experiments which I carried on during the last two winters. The results are presented in this paper for any suggestions they may offer other workers, but it should be emphasized that this is a preliminary report, and that future experiments may modify some of the ideas presented here.

In the preliminary experiments, oysters were kept in aquaria at 25° and 30°C. for periods of 30 and 35 days, but better gonad development occurred in later experiments in which the temperature was held between 22° and 26°C. for periods of 20 to 30 days. Nevertheless, apparently normal straight hinge larvae have developed from fertilized eggs

of oysters induced to spawn after only 10 days at 30°C. and after only 15 days at 25°C. Although fertilizable eggs and active sperm have been obtained at these conditioning temperatures in much shorter periods, normal spawning could not be induced. A more complete report on the relation of temperature to gonad development is now prepared for publication by Loosanoff and Davis.

Aquaria having a ratio of about 4 liters of sea water per oyster and a rate of flow sufficient to give at least four changes of water per day were maintained in later conditioning experiments.

In the early experiments eggs and sperm were taken from conditioned oysters by stripping. On April 25, 1947, however, it was noticed that some oysters had spawned in one of the conditioning tanks and that the eggs were developing normally. This was the first indication that the conditioned oysters would spawn or could be induced to spawn.

After this observation nearly all subsequent experiments were with eggs and sperm from oysters induced to spawn, by rapidly increasing the temperature from that of the conditioning tanks to 30° or 32°C., or by the addition of sexual products. Temperatures higher than 32°C., however, have not been found effective and in some instances have seemed to inhibit spawning. Prytherch used high temperature to induce spawning in the summer of 1924 and Galtsoff in 1938 and 1940 describes this and various other agents used to induce spawning of oysters.

On November 25, 1947 the first conditioned oysters of the fall were opened without attempting to spawn them. Some of the males and females had ripe gonads. During the latter part of January and during February several groups were induced to spawn and since March 1st, at least one group per week has been spawned. Nearly every oyster, in the latter experiments, was induced to spawn and was spawned two or more times at intervals of four or five days. Few eggs were obtained after a third spawning and, when opened, the oysters appeared "spawned out".

Spawning in the conditioning tanks has been observed on several occasions. In the 30°C. tank, for example, mass spawning occurred on the fourteenth day with no apparent external stimulation, i. e., the temperature remained constant and no sperm or eggs could possibly have been introduced from outside. An accidental increase of two or three degrees centigrade has been followed by an observed light, possibly premature spawning on the ninth day in the 22° to 26°C. tank.

Unintentional introduction of sperm or eggs from a beaker or thermometer used about the spawning table and returned to the conditioning tanks can also result in unscheduled spawnings. On several occasions the presence of white feces composed almost entirely of sperm has been the only indication of a spawning that has occurred in the conditioning tanks during the night. In one group of oysters kept at 30°C. for 30 days, although the only observed spawning was

the mass spawning on the fourteenth day, at the end of the 30-day period all oysters were found to be spawned out. Undoubtedly several lighter unnoticed spawnings had occurred. In many cases it was found difficult, if not impossible, to keep the oysters in the conditioning tanks for long periods without having such unscheduled spawnings.

It is now believed that the relatively poor condition of some of the oysters in the early experiments, as manifested by the very thin gonadal layer and almost complete lack of glycogen, was a result of spawning out during the 30 to 35-day periods of conditioning at the high temperatures.

It has been established that it is not necessary for the oysters of the Long Island Sound region to undergo hibernation before gonad development can again be induced. Spawned oysters taken from Milford Harbor on October 17th, when the outside water was still well above the temperature at which oysters hibernate, were induced to develop ripe gonads when conditioned at temperatures of 20°, 25° and 30°C.

Experiments are now in progress to determine whether oysters that have been induced to develop gonads and spawn during the winter months will again develop gonads and spawn during the regular spawning season. Other experiments are planned to determine just how soon after being spawned out, oysters will again develop new, ripe gonads. It is also planned to determine more accurately just how early in the fall gonad development can be induced.

Another technique was tried that holds some promise of supplying spawn for the late summer and early fall experiments after it cannot be obtained from the oysters living under natural conditions. On August 13th a group of oysters, brought into the laboratory from deep water, was placed in an ordinary electric refrigerator at about 5° to 7°C. Although the conditions of the experiment were rather crude and the oysters suffered considerable dehydration, fertilizable eggs and active sperm were obtained from them as late as September 30th, after 45 days of refrigeration. Living larvae from these oysters were maintained in the laboratory at Milford as late as October 11th.

Male oysters were induced to spawn normally up to and including the 37th day of refrigeration. In fact, one male spawned more or less normally even after 42 days of refrigeration. Though no oysters could be induced to spawn later than the 42nd day, on the 45th day when the experiment ended, it was still possible to secure active sperm by stripping.

Female oysters were induced to spawn normally after as long as 20 days of refrigeration. A few eggs were discharged on the 37th day and again on the 42nd day, but spawning in these cases was abnormal. Eggs were obtained by stripping on the 37th, 42nd and 45th days, and some in each case were fertilizable. However, on the 37th and 42nd days some of the eggs appeared shrunken, probably due to dehydration, and on the 45th day some of them had portions of the membrane and bits of cytoplasm missing from the margin. This suggests that resorption may have begun by the 45th day, but the abnormalities observed may have been primary or secondary effects of dehydration.

It seems probable that dehydration, due to refrigeration, interfered more with the spawning mechanism of the female than with that of the male oyster. This should not be surprising since the female normally forces the eggs through the tiny openings of the gills into the mantle cavity and then ejects them by a clapping motion of the shells, while in the male the sperm pass directly from the gonaducts into the cloaca and are carried out by the excurrent water pumped by the oyster.

Larvae of one culture, from the seven-day group, were the only ones from the refrigerated oysters to reach the setting stage. However, many larvae from the 23-day oysters grew to the 150-200 micron, medium umbo stage, and larvae from the 30 and 37-day oysters grew to early umbo stages, many living for 20 days or more. The 42 and 45-day groups gave normal ciliated larvae but they did not develop into normal straight hinge stages. Some abnormally small straight hinge larvae were found in these cultures but most larvae either failed to develop a shell or the shell formed was not normal. Probably all larvae that reached the normal straight hinge stage should be considered viable, since even during the regular spawning season larvae could not invariably be carried beyond this stage.

A different type of refrigeration, such as running sea water at 5°C. or less, would not cause dehydration and would carry away waste products of metabolism. This should keep the eggs in more normal condition, thereby resulting in more normal larvae. It might also prolong the period during which the refrigerated oysters could be induced to spawn normally. By such improved refrigeration methods it should be possible to extend the period during which spawn may be obtained certainly for one or two months, perhaps longer. This will be determined next fall.

It is believed that, with the experience gained this year, a dependable supply of oysters in spawning condition can be maintained in the laboratory throughout the year to provide spawn for larval studies. By using the refrigeration technique, oysters with active sperm and fertilizable eggs have been kept in the Milford laboratory as late as September 30th, and by the use of heated conditioning tanks, they have been induced to develop gonads as early as the 25th of November. It appears probable that the two methods can be further developed to have spawning oysters continuously throughout the year.

II. Methods for rearing oyster larvae under laboratory conditions

Work on methods of culturing oyster larvae has been directed toward devising a standard method by which larvae can be grown to the setting stage. As yet no completely satisfactory method has been devised, though some progress has been made in that direction.

Thus far, all methods designed to maintain a continuous flow of sea water have been found unsatisfactory. Several methods have been found to retain the larvae and give a fairly satisfactory flow of sea water, but cause the larvae to congregate near the overflow. Though

some larvae live as long as 18 days in such cultures, they fail to grow beyond the straight hinge stage and eventually all die.

The most satisfactory results have been obtained by changing the sea water in the culture jars daily, retaining the larvae on stainless steel nesting screens of 100, 250 and 325 meshes per inch. To start the culture the fertilized eggs are placed in clear sea water and aerated rather strongly. If the temperature is maintained between 19° and 24°C. and the culture is clean, that is, without too great an excess of sperm and little or no blood and tissue cells, it can be left as long as 48 hours without fouling. Under less favorable conditions the first change of sea water should be made between the 24th and 36th hours.

If the eggs are mature and in good condition, the larvae should have shells that completely cover them, that is, be in the straight hinge stage, by the 18th to 36th hour. They will usually be large enough to be retained by the 325-mesh screen and be strong enough to withstand screening by the 24th to 36th hour. After the first 48 hours the water in the culture jars is changed daily by filtering it through the set of screens. The larvae are retained on the screens and are returned to the culture jars, which are then filled with fresh, cotton-filtered sea water. Copepods and other larger forms are retained on the 100-mesh screen and can be discarded until the larvae become large enough that they too are retained by the 100-mesh screen, after which, of course, all material retained by the screens is returned to the culture jars.

During 1947-48 billions of oyster eggs have been collected, fertilized and successfully carried to the straight hinge stage by this method. In some cultures as many as 2,000 larvae per cubic centimeter were brought through the first 48 hours in this fashion with no apparent harmful effects from overcrowding. Generally, however, numbers have not exceeded 500 larvae per cubic centimeter. There is some evidence that larvae 3 days old and older are overcrowded when present in concentrations above 100 to 200 per cubic centimeter.

It seems strange that in a few cultures some larvae reached the setting stage and that in a number of cultures some larvae developed to the medium umbo stage, 150-200 microns in size, while in other cultures under apparently identical conditions none of the larvae showed any increase in size after reaching the 75 micron, straight hinge stage.

While the screening method has been the most satisfactory tried, it does not enable the larvae to grow and develop to the setting stage in most cases. One change of water per day may not be sufficient to remove the waste products of larval metabolism, or, more likely, one change of water per day does not introduce enough food to support larvae in the concentrations necessary to be practical for laboratory work and experimentation.

Supplementary feeding with pure and mixed cultures of possible food organisms has been tried with no noticeable difference in growth or survival over larval cultures not receiving supplemental feeding. Some of

the forms used, such as Chlorella, can definitely be seen in the stomachs of the larvae but do not seem to be utilizable. Wells in the summer of 1925 was able to grow larvae to the setting stage and does not seem to consider supplemental feeding necessary, while Cole and his co-workers in England, in their tank experiments reported in 1936, make constant use of enrichment with apparently excellent results.

In our experiments more summer cultures of larvae show growth beyond the straight hinge stage than do the winter cultures. Even in summer, however, certain periods seemed much more favorable than others for growth of larvae. Perhaps, except for short periods, natural sea water does not contain sufficient suitable food for the high concentrations of larvae necessary for practical laboratory cultures. It would seem that food organisms are the variable factor most likely to fluctuate in this manner. It is to find a practical supplemental food, or foods, to overcome this difficulty and permit us to rear larvae to the setting stage throughout the year, without regard to lack of food organisms in natural sea water, that our present work at Milford Laboratory is directed.

# THE REARING OF OYSTER LARVAE IN PONDS AND TANKS, ITS PROBLEMS, ITS PROSPECTS

Dr. P. Korringa

Biologist, State Institute for Fishery Research
Bergen op Zoom, Holland

One of the main targets in oyster culture is to raise the production of spat. Though every oyster produces hundreds of thousands of larvae annually, very few of these larvae succeed in settling down on a suitable piece of substratum, and thereafter survive the perilous first months of their sedentary existence.

Quantitative studies carried through in the Dutch oyster centre, the Oosterschelde, demonstrated that under favorable temperature conditions only about 5% of the larvae produced reaches the mature stage, ready for fixation. At temperatures below 19°C. the percentage is still less. Our oyster farmers offer the mature larvae millions of tile collectors and thousands of cubic metres of mussel shells on which only about 1% of the mature larvae succeeds in finding a suitable piece of substratum to settle on and attach, while the remainder perish. In the first few months of sedentary life about 9 out of 10 young spat are killed by smothering sand and silt or by starfish; others are destroyed by creatures of a more stalwart nature.

Yet, the Oosterschelde can be reckoned among Europe's most prolific spat producing centres, together with the Gulf of Morbihan and the Basin of Arcachon in France. In many other oyster districts of Europe no spat-fall of commercial magnitude can be obtained today where rich natural oyster beds once were encountered. The reasons spat production became negligible are (1) a reduced stock of mother oysters producing too few oyster larvae, and (2) the dispersing action of the currents, which scatter the few larvae so much that collectors placed in these waters are only found by an occasional mature larva, so that spat producing operations cannot pay. In such regions one often pondered over the possibility of rearing oyster larvae in ponds or tanks. In such enclosed basins the dispersing action of sea-currents has been eliminated and predators are kept down adequately, so that even a relatively small number of larvae could lead to a profuse setting on the cultch placed in the ponds. Moreover, any protraction of the pelagic phase, owing to low water temperatures, could not easily produce a fatal effect as so often proved to be the case in open waters, where the daily toll levied on the larvae is heavy.

Though theoretically no reasons can be conceived why the rearing of oyster larvae in tanks should be reckoned among the impossibilities, the many attempts made usually led to failure, sometimes alternating with an occasional very moderate success.

As France and Holland possess rich oyster producing centres, these two countries were never in a dire need to develop a system for rearing oyster larvae in tanks and the same holds good for the U. S. Recently other considerations came to the fore. Our methods of oyster culture are well established, approved, and highly differentiated, but so far little attention has been paid to the possibility of selecting special strains of oysters characterized by superior qualities in growth, flavor, resistence to diseases, and so on. We may rest assured that research on heredity and selection in oysters eventually will yield important results to the oyster industry. In such research one ought to be able to rear the larvae of limited numbers of well selected oysters, and to this aim reproduction in ponds or tanks, or in the laboratory is the only feasible method.

Important experiments carried through at Port Erin, in which oyster larvae were kept in glass plunger jars, placed in dim light, demonstrated that oyster larvae require small naked nannoplanktic flagellates as food. When feeding larvae pure cultures of flagellates, one eventually succeeded in rearing to settlement about 90% of the larvae originally introduced into the jars.

Most probably the many failures in rearing oyster larvae in tanks and ponds should be ascribed to a lack of adequate quantities of the appropriate naked flagellates, so that the oyster larvae suffered from starvation and died. One should remember that the density of larvae in the tanks is far greater than in open waters, so that the number of food organisms must be commensurately high. Therefore we understand why the results of the many experiments carried through in the U. S., in which the rearing tanks were fitted with a regular supply of normal sea water, were discouraging so far.

British investigators working along other lines, sustained their efforts and after many years of more or less complete failures, they developed an adequate and reliable system to produce oyster spat in tanks. The principle of their system is to use stagnant water and to offer the larvae an abundance of naked nannoplanktic flagellates. It is Dr. H. A. Cole of the Conway Fisheries Experiment Station who should be given credit for inventing the enrichment of the water with minced shore crabs, which leads to a rapid development of the required flagellates, so that the oyster larvae in the tanks can develop and settle. Dr. Cole worked mainly along empirical lines. He demonstrated that absence of adequate food has probably been the cause of so many earlier failures, and not unsuitable temperatures or salinities. Dr. Cole told me that he repeatedly observed that differences in the viability of the larvae used may interfere more or less with normal development. He was not in a position to explain, however, why development and setting regularly was accomplished in the Conway mussel purification tanks which are about 8 feet deep, and why the same methods practically always lead to failure in tanks half as deep.

In 1946 one of our oyster farmers asked me to conduct an effort to produce oyster spat in his basin at Tholen. Though this offered me a welcome opportunity to get acquainted with the tank breeding technique, following Cole's approved prescriptions, I saw immediately two reasons for a possible failure. In the first place we could never dispose of offshore water in Tholen, so that it might prove to be impossible to raise the number of flagellates without calling forth a rapid multiplication of weeds like non-motile algae and diatoms. In the second place the basin at Tholen was only about 4 feet deep. We could not dispose of tanks of a depth of those at Conway.

I was successful in producing a dense culture of nannoplankton flagellates by scattering regularly some minced shore crabs in the tanks. The flagellates developed so well that the water soon acquired a green hue, which ultimately even concealed to the eye the bottom of the tank, 4 feet deep. Non-motile algae and diatoms were rare in the course of the experiment. This favorable development demonstrated that the unsuitability of shallow tanks, recorded by Cole, need not be ascribed to the impossibility to raise the number of small flagellates in them.

In the course of my experiment oyster larvae were amply produced by the mother oysters present in the tank. Temperature and salinity fluctuations remained within normal bounds so that conditions were apparently highly favorable.

Contrary to expectations the larvae in the basin did not develop at all, soon decreased in numbers and showed features of ill-health. Large and mature larvae were not observed at all; no spat settled down on the cultch laid out in the basin. The 1946 experiment was a complete failure.

Which factors can be held responsible for a failure like that? Food was abundant, and salinity, temperature and pH left nothing to be desired. To investigate whether oxygen could have shown a deficiency detrimental to the tiny oyster larvae, I measured the quantity of oxygen present in the water near the bottom and near the surface of the experimental tank. It may be assumed that during broad daylight flagellates produce ample oxygen by the process of carbon dioxide assimilation, but that they consume oxygen, like the oyster larvae, the adult oysters and other creatures during the dark hours of the night. This principle was corroborated by a series of observations carried through during 24 hours. Though a marked drop in the quantity of oxygen could be observed in the second part of the night, the values measured in the tank always remained higher than those observed simultaneously in the open Oosterschelde. Therefore it was considered highly improbable that a lack of oxygen could have been the cause of the 1946 failure in rearing oyster larvae in the experimental tank.

I studied the swimming behaviour of the larvae by placing them in glass dishes and glass tubes of different lengths in the laboratory, where they have been fed with pure cultures of flagellates. Conditions in Norwegian oyster polls with their layer of fresh water overhead and their bottom layers devoid of oxygen, demonstrate that oyster larvae need not

rest on the bottom or at the surface film during pelagic life. Yet, I observed that oyster larvae take a rest now and then. They swim about for several minutes and then come down motionless, sometimes with their valves closed, at a rate of 0.8 cm/sec., often with their velum expanded like a little parachute, at a rate of 0.4 cm/sec. They seldom dropped for more than 50 cm., in succession and usually started swimming upwards again after dropping for half a minute. Moreover larvae dropped on the bottom could easily rise again, and were by no means trapped on the bottom. I cannot see how this typical swimming behaviour of oyster larvae could be held responsible for their failure to develop normally in a tank of about 4 feet deep.

Is there another factor showing abnormal values under tank conditions? I believe there is one. My oxygen measurements demonstrated that the quantity of oxygen present in the tank was actually higher than in open water and in fact supersaturation prevailed in the tank. The same holds good for conditions in my glass tubes in the laboratory. Could it be that a surplus of oxygen is injurious to oyster larvae?

I decided to make an effort to keep the oxygen level down to more normal proportions in a new experiment, carried through in 1947. As the oxygen in the tank is produced by the flagellates, I thought it might be feasible to check oxygen production by keeping the number of flagellates within bounds. The latter could be achieved by adding fewer crabs. The data on the 1947 experiment demonstrate that my premise was right. By adding fewer crabs a more modest number of flagellates made their appearance. The water acquired a green hue, but the bottom remained visible. This resulted in a more modest oxygen production during the daylight hours, but seldom supersaturation values were observed. The course of events during 24 hours sampling resembled that in the year before, but was performed at a lower level, closer to that observed in the open Oosterschelde. For comparison purposes I once carried through 24 hours oxygen sampling in the centre of the Oosterschelde, and found that the same daily rhythm in oxygen could be found here, but with a far narrower amplitude than in the tank, no doubt because the number of flagellates in the tanks was more than 10 times as high as in the open Oosterschelde. Supersaturation values were not observed by me in the open Oosterschelde.

What has been the result of this difference in oxygen production in the experimental tank? Temperature, salinity and pH were normal once again. The oyster larvae appeared, they developed rapidly, large and mature larvae were seen in great numbers, a heavy setting occurred on the collectors placed in the tank. On one of the tiles I counted 900 spat.

This led me to believe I had found the key to open up spat production in shallow tanks. One should provide for ample production of small naked nannoplanktic flagellates to feed the oyster larvae, but the production of flagellates should be kept within bounds to avoid the development of too extreme conditions injurious to oyster larvae.

At first I thought that it could be oxygen itself which impaired the larvae. I could not produce convincing evidence for this view, however. Though a modest oxygen production in the tank and successful larval development and setting ran parallel in the year 1947, it did not follow that oxygen itself was the limiting factor in 1946. A high level of oxygen points at vigorous carbon dioxide assimilation. As in 1947 the number of flagellates has been kept down to about 1/3 of the number reached in 1946, it is easily understood that assimilation and oxygen production demonstrated a lower level in the 1947 experiment. Apart from oxygen other products of assimilation are released by flagellates and kindred minute organisms. It is known that various dinoflagellates produce highly toxic metabolites during assimilation. Recent investigations carried through by Loosanoff and Engle demonstrated that several phytoplankton organisms, if kept in dense cultures, excrete products in quantities noxious even to adult oysters. Several other cases of toxic metabolites produced by phytoplankton organisms are known now. Therefore I am inclined to assume now that too dense populations of flagellates in experimental tanks hamper the development of oyster larvae by producing dangerous quantities of toxic excretes. A high level of oxygen is only an indicator of too vigorous assimilation activities, which may lead to concentrations of external metabolites injurious to oyster larvae.

This view corresponds with some successful experiments in the rearing of oyster larvae in which high concentrations of flagellates have been offered to the larvae, while assimilation has been kept down adequately. This was attained in the Port Erin plunger jars kept in dim light, and supplied with pure cultures of flagellates, and in Dr. Imai's recent experiments in Japan, in which light is prevented from entering his experimental jars and tanks, and colourless flagellates, fed with starch, are used as an adequate source of food.

I am anxious to learn the secret of the deep tanks at Conway. Obviously conditions injurious to oyster larvae do not easily develop there. Could it be because scanty illumination in the lower half keeps down the number of flagellates? In fact Dr. Cole regularly observes the same number of flagellates in his tanks as I did in my 1947 experiment. Further investigations in the laboratory and in tanks are required before we can state that we know all about it.

The results so far obtained are encouraging and promise to open up the wide, so far unexplored field of heredity and selection in the oyster, which ultimately may yield most important practical results to the oyster industry. We should steer clear of the rocks by offering the oyster larvae ample nannoplankton flagellates but prevent a too intense assimilation of the food organisms leading to injurious concentrations of external metabolites.

# EFFECTS OF FLOOD CONDITIONS ON THE PRODUCTION OF SPAWN IN THE OYSTER

Dr. Philip A. Butler

Aquatic Biologist, U. S. Fish and Wildlife Service

The effects of seasonal floods on oyster bars have been subject to investigation for many years at various locations along the eastern seaboard and in the Gulf of Mexico. The damages caused by these fresh waters usually have been observed several months after the actual environmental changes took place, when local watermen working the area discovered extensive mortalities. Such a disaster was reported at the last meeting of this convention, when Messrs. Beaven and Engle described the effects of the floods of 1945-46 in the upper Chesapeake Bay. These floods caused the death of nearly 70 per cent of the oysters in the area and apparently were quite similar to the floods which had caused high losses here several times in the past century.

During the spring of 1946 we were able to collect oyster samples regularly from the bars which were located nearest to the entrance of the flood waters from the Susquehanna watershed into Chesapeake Bay. Consequently, the opportunity presented itself to study microscopically the changes in these oyster meats and see what effect there had been on the production of spawn.

When the collection of samples was initiated in May of 1946, it was possible to find from 50 to 100 oysters per bushel of dredged shells, but by the end of that same summer it was necessary to examine from 2 to 3 bushels of shell in order to obtain 25 live oysters for examination. The oysters were characterized by the cleanliness of the shells. Most of the usual fouling organisms had been killed also by the fresh water and washed away. The oysters themselves were swollen and nearly transparent; many were unable to close their shells tightly. The muscle of the oyster was scarcely attached and the meats could be pushed out of the shells without using a knife. Local fishermen reported that on past occasions, the muscles have become entirely loosened and the oyster meats have been seen floating in windrows on the surface water over the bars. Determinations of the water content of the oyster meats showed that in many samples the total solids had been reduced by as much as 50 per cent.

Of the many oysters examined, about 10 per cent had the normal opaque, creamy-white appearance and would have passed as poor to fair market quality. But these, as well as the "glassy" oysters, always had empty stomachs and gave no evidence of feeding activity. A majority of those examined revealed heavy deposits of the green copper compound in the palps and gills and throughout most of the mantle.

In order to interpret the changes in these oysters, duplicate samples were collected at weekly intervals in another part of Chesapeake Bay where the oysters appeared to be quite "normal" and the salinity of the water was only moderately reduced by the floods. In this higher salinity area, the oysters were of good market quality. During the summer there was a commercial set of young oysters in this area indicating that the population had spawned normally.

The changes which were found on microscopical examination of the oysters from the low salinity area can be best understood if we describe first what normally happens in the production of spawn. This process has been fully described by Dr. Loosanoff for oysters in Long Island Sound and only the principal stages will be mentioned here. In the late summer, when spawning is usually complete, the gonad goes through an indifferent stage and it is difficult to tell from these resting cells whether the oyster is male or female. This period is of very short duration and when the oysters are feeding heavily in the fall, the spawn for the following summer starts to grow and the sexes of the oyster are readily distinguishable. Few changes take place during the winter hibernating period. In the spring, as water temperatures approach 40°F., the oyster commences feeding again and the spawn develops very quickly. Final differentiation of the spermatozoa takes place and the deposition of yolk in the eggs is completed. In the Chesapeake Bay area, larvae may be found in the water by the end of May, but the actual time of their appearance varies from year to year and with the latitude. The eggs continue to ripen and spawning goes on for most of the summer until the end of August, when once again the oysters are spawned out and the gonads go into the resting stage. Although there is considerable variation among individual oysters as to the time when they achieve "ripeness", in this area at least, it appears that there are two major spawnings during the summer and also a small but continuous production of larvae during the entire period.

In contrast to this course of events in the high salinity area, nearly half of the oysters examined from the flooded area during the months of May, June and July had gonads which were in the resting or indifferent stage, that is, the stage of activity they should have shown 8 to 10 months earlier. Another 40 per cent had developed just enough so that their sex could be determined and a scant 10 per cent had spawn that approached the ripeness of oysters from the high salinity area. After the first week in August, however, there was an abrupt increase in the development of spawn in the oysters from the low salinity area. The gonads rapidly increased in thickness, and free-swimming larvae were found in the plankton samples. Then, from the middle of August until late December, the same development of spawn took place which had occurred in the oysters of the high salinity area during the period May through July.

In Figure 1, the development of spawn in the two areas has been graphed to illustrate this differential in gonad development. The sequence of stages is, of course, the same for each group. Each point on the graph represents the dominant stage of gonad activity which was

found in the sample of oysters in any one period. Each sample was made up of from 10 to 40 oysters collected over a two weeks or longer period. The striking change which took place during August in the LS or low salinity group corresponds precisely with the salinity increase shown in the line graph in Figure 2, which depicts the seasonal fluctuation in salt content in parts per mille for the area.

Correlated with the sudden development of spawn in August in the flooded area were two very obvious factors. The salinity, which until that time had been fluctuating between 0 and 3 parts per mille, jumped to 6 ppm and then more gradually increased to 13 parts per mille. The second factor was that the oysters started feeding actively. It should be mentioned here that the bottom water temperatures in the two areas studied did not vary more than 1°C. throughout the period and it is assumed that temperature was of no significance in the delay of gonad development in the low salinity area.

Now in discussing the cause for the delayed production of spawn there is no doubt that the fresh water was the underlying factor but it appears that there is more to the problem than salinity alone. It will be recalled that from early last spring, about 10 per cent of the oysters were in better condition than the remainder, i. e., not so transparent in appearance, and also that approximately this same percentage produced mature eggs at the normal time in the spring. Since neither this group or the remaining 90 per cent were feeding during the first half of the summer, it is suggested that the direct cause for the spawning delay was the absence of stored food. The 10 per cent group had maintained sufficient stored glycogen to permit the normal development of spawn and this activity was not prevented by the presence of the fresh water. Then when the salinity increased in August, the remaining oysters started feeding and immediately began to develop mature sex products. It is of interest that no abnormalities in gonad development were found either in the small group which ripened early or in the majority which matured late in the summer. This again indicates that fresh water, in itself, does not directly affect the production of spawn in the gonad.

The first reaction of the oyster to fresh water is to close its valves tightly, automatically cutting off its food supply. Hence, the survival of the animal and its ability to reproduce is going to be a function of how long it can exist without additional nourishment. The more reserve food it has on hand in the form of glycogen, the better will be its chances for not succumbing to seasonal flood conditions. There are, of course, factors concerned here other than the simple fact that the shells may be kept closed. The decreased food supply might just as well be due to absence of food from the water, or to the inability of the oyster to collect it because of impairment of ciliary action, or even to the oysters' inability to digest food when it is so swollen from the absorption of fresh water. In the final analysis, however, the delay in the production of spawn would appear to be the result of tissue starvation.

The small group of oysters which survived better and did produce spawn normally are of considerable interest to us. The reasons for their having had more stored food than the majority of the population are not clear, but if we may assume that this sample was representative of oyster populations in general, we have a better understanding of the "comeback" which many oyster bars have staged in the past. In these cases, oyster bars which had become suddenly barren through natural causes have been observed a few years later to be densely populated with young oysters. The remnants of the former population because of their inordinate productivity were able to cope with such natural disasters in a relatively short time and thus perpetuated the species.

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# SPATFALL PREDICTION IN HOLLAND

Dr. P. Korringa

Biologist, State Institute for Fishery Research
Bergen op Zoom, Holland

The oyster farmers all over the world are faced with the problem of deciding when to plant cultch so that it shall not be silted over or covered with organic growth before the oyster larvae are able to attach. This problem is of paramount importance in regions where the kind of cultch used is rather expensive, and where the preparation and the planting of cultch requires a good deal of manual labour. The higher the price of labour the greater the necessity to ensure a good spatfall on the cultch used. Therefore a reliable scientific system to predict the intensity of setting of oyster spat is of great importance in regions where manufactured collectors (e.g. tile collectors) are widely in use.

The events in the Dutch oyster centre, the Oosterschelde, give a vivid illustration of the growing demand for adequate information on spatfall prospects. The old timers in the 19th century used to place a great many tile collectors but, even in seasons characterized by good setting, only a limited percentage of these tiles bore the maximum number of spat. Often up to 2/3 of the tiles were placed ashore in the fall, as it was not considered worth while to attend any further to the mere sprinkling of spat they carried. The oyster farmers tried to overcome this disadvantage by placing "test-collectors". Small numbers of tiles were placed at intervals and as soon as these tiles were found to be covered with spat, the oyster farmers started to plant their entire supply of collectors. As the spat can only be seen with the naked eye about a week after attachment, it goes without saying that this method frequently led to disappointments, the best time for setting often being over when the cultch was planted. In later years the number of tile collectors in use in the Dutch oyster region greatly diminished and in their place shells were scattered over the beds, a cheaper kind of collector requiring little care.

A crisis in the Dutch oyster industry in the years following 1930, caused by an explosive propagation of the slipper limpet and a sudden aggravation of shell disease, compelled Dutch oyster farmers to abandon spat collecting with shells and to revert to tile collectors. In this difficult period the Dutch Government assisted the oyster farmers in various ways, one of which was the establishment of a service to predict the intensity and the time of setting, by which the chances to obtain a satisfactory setting greatly increased. Dutch oyster farmers are, as a rule, very modern-minded people and they immediately seized this opportunity to acquire adequate information on spatfall prospects. The result has been that seldom, if ever, tiles are brought ashore because they show an insufficient number of spat. Of course there are

differences in the intensity of setting from year to year, but the difference in output between the various batches of tiles are greatly reduced nowadays. Since the oyster farmers do their utmost to place all their collectors in the period indicated by us as favourable for setting, they are approaching the optimum catch of spat under the given natural conditions.

Nowadays to collect a given number of spat, the oyster farmers need only about 1/3 of the number of tiles and 1/3 of the expenses for labour and transportation that they would have needed without spatfall prediction under the same natural conditions. This clearly demonstrates the economic importance of spatfall prediction in regions where tile collectors or other manufactured cultch are in use.

What are the basic principles of a system to predict the intensity of setting?

First of all a thorough knowledge of hydrographic conditions of the region concerned is required. One should be familiar with local tidal movements such as the speed of water currents and the degree of water renewal during a tidal cycle. Further salinity conditions and water temperatures are very important factors in pelagic life and setting of the oyster.

Next one should be familiar with the behaviour of the oyster larvae during pelagic life. It is important to know whether or not the larvae remain uniformly distributed during any part of day and night, during any phase of the tidal cycle and under any kind of weather.

Further it is important to know how long the pelagic phase lasts at different temperatures and what percentage of the larvae may settle down under different conditions. The greater the knowledge acquired on quantitative relations between the number of young larvae encountered in the plankton, the number of mature larvae ensuing, and the following intensity of setting, the greater the accuracy of spatfall predictions.

In Holland quantitative plankton samples are procured twice a day in summer by straining exactly 100 litres of water pumped at high and at low tide in a fixed station. All the oyster larvae present in these samples are counted and measured. The number of young larvae present in the samples is a reliable measure for the emission of larvae by the mother oysters lying on the beds.

The percentage of the larvae reaching the so-called "mature" phase, ready for fixation, greatly differs according to environmental conditions prevailing during pelagic life. In the Oosterschelde water temperature proved to be the predominant factor in this. Fluctuations in the quantity of food are only of secondary importance here. I repeatedly observed that the number of naked nannoplanktic flagellates, the basic food for the oyster larvae, did not differ much in the course of the summer season. This does not imply that food conditions cannot be the limiting factor in larval development in other centres of spat production.

With the temperature conditions largely the predominating factor in the Oosterschelde, spatfall prediction is not too difficult when the production of young larvae is regularly checked.

A far greater degree of accuracy in predicting is attained by following closely the development of the pelagic larvae, which is done by measuring all the larvae present in our samples. The number of grown-up and mature larvae present in the samples provides an excellent measure for the intensity of setting in the next few days.

Thus the number of young larvae recently produced served to predict the approximate setting about 10 days ahead. Data on the subsequent growth and development of these larvae are used to prepare predictions on shorter notice with a greater degree of precision. As a measure of control, spatfall is measured quantitatively throughout each summer season. The data thus obtained are of great importance in consolidating the basis of our prediction system. The practical results obtained led the Dutch oyster farmers to attach great value to our predictions and none of them plants his cultch without consulting our bulletins.

However important our predictions on short notice are, it would be a great help if we could predict ahead the amplitude and periodicity of larval production. Scrutiny of our quantitative data collected in several consecutive years, demonstrated that the establishment of such a long term prediction is not chimerical!

Fluctuations in the number of larvae produced from year to year proved to be closely correlated with the number of mother oysters present on the beds. When a year is characterized by a limited production of larvae, only a really warm summer, resulting in a high percentage of the larvae reaching maturity, can lead to a profuse setting. If a year is characterized on the other hand by an ample production of larvae, the chances for a good setting are far greater, as even at moderate temperatures a fair number of mature larvae can be expected. Temperature conditions and food determine the percentage of larvae reaching the setting stage, but it is the initial number of young larvae which determines how many mature larvae will occur and with what spatfall prospects. Therefore it is of paramount importance to prevent a serious reduction of the number of mother oysters in the spat production centres.

Still more interesting was our finding that a correlation exists between the ups and downs of larvae production in the course of each summer and the moon's phases. Maxima in the production of larvae can be expected to occur about 10 days after new and full moon. Incubation requiring about 8 days in Ostrea edulis, we can deduce that spawning apparently shows its maxima at both of the spring tides. One of the maxima prevails largely and, curiously enough, could be located between June 26 and July 10 in every year under consideration (1935-1947). This led to the formula, valid for the Oosterschelde: "The big maximum in swarming is to be expected between June 26 and July 10, about 10 days after full or new moon".

In case high water temperatures prevail in that period, an excellent spatfall can be expected some 8 to 10 days later. When it happens to be unusually cold, even the ample production of larvae of the big maximum cannot lead to a fixation of commercial magnitude, and one should wait for the next maximum in larvae production, a fortnight or 4 weeks later. If any doubt remains, predictions on short notice, based on plankton investigations serve as a reliable guide to spat-collecting operations.

These are the leading principles of spatfall prediction to-day.

# SHELL DISEASE IN OSTREA EDULIS - ITS DANGERS, ITS CAUSE, ITS CONTROL

Dr. P. Korringa

Biologist, State Institute for Fishery Research
Bergen op Zoom, Holland

Complaints concerning a mysterious disease in the Dutch oysters were heard on all sides in the years following 1930. Green, rubber-like spots and warts appeared in the formerly spotless shells, many oysters suffered from seriously deformed shells, and mortality, especially among the young oysters, rose alarmingly.

The green spots were soft and elastic like rubber which led many to believe that the diseased oysters were apparently incapable of secreting normal hard shell-layers, or even that the calcareous substance had been dissolved after its deposition, leaving behind conchyolin, the organic material interwoven with calcareous matter in mollusk shells. The quantity of conchyolin in mollusk shells is very modest, however, and after artificial decalcification only some thin remnants are left behind. The green warts, though apparently consisting of conchyolin, could not be explained by a mysterious disappearance of the inorganic compound of the shell, but could only be accounted for by assuming a local abnormally intense secretion of conchyolin. As the mollusk shell is inanimate itself, like man's hair and nails, investigations to clear up the cause of abnormal shell secretion should focus on the living tissues of the oyster and notably on the mantle epithelium, which is in charge of secreting the shell.

Laboratory investigations - carrying through histological observations on healthy and diseased oysters, my serial sections showed that the mantle epithelium normally consists of small nearly cubical cells, interspersed with small unicellular glands. In one place, however, opposite the ligament which connects the valves, very high and slender cells were found to compose the mantle epithelium. The oyster's ligament, consisting of a tough rubber-like material, is apparently secreted in successive layers by those high slender cells, while the small cubical cells with the interposed glands are in charge of the secretion of the calcareous part of the shell.

Opposite the green warts and spots in diseased oysters I found a mantle tissue consisting of the very same high and slender cells which secrete the ligament in healthy oysters. For some still obscure reason diseased oysters proceed to secrete the normal green, rubber-like ligament material on abnormal places in the shell and in abnormal quantities.

Death appeared to be threatening in case the diseased spot was situated under the muscle scar. Then often large parts of the muscle tissue appeared to be replaced by the typical diseased mantle tissue, thus dangerously interfering with the oyster's shell movements. In case the disease happened to be located along the shell's edges, normal shell growth was impossible. Many oysters died, others were seriously disfigured and could never grow up to a normal marketable oyster.

Further it could be demonstrated that the formation of the green spots and warts was a symptom of an advanced phase of shell disease. Earlier symptoms were cloud-like spots of a chalky white colour, contrasting with the pearly lustre of the normal shell and not to be confounded with the so-called chalky deposits, which are thick and porous. The white clouds in the shell's interior proved to be preceded, in their turn, by tiny specks of a chalky white colour of the size of a pin's head. These tiny white specks, the first symptom of shell disease to be observed with the naked eye, could be found in oysters of different age groups. Even oyster spat, a few months old, often appeared to show these specks and were thus marked as diseased in their early youth.

Laboratory investigations could not easily bring us much further than revealing macroscopic and microscopic characteristics of this disease.

Field investigations - only field observations and deliberate experiments carried through under natural conditions could give the answer to the multitude of questions which arose. First of all it was necessary to clear up the epidemiology of this disease. It should be known where and when the disease spreads, and what is its course under different external conditions.

The factor place - to find out which part of the oyster beds were the heaviest infested by shell disease and whether certain parts of the Dutch oyster beds happened to be free of it, I examined a great number of samples of spat. After having found out that the number of white specks shows no further increase after about October 1st, I collected samples in October and November and examined them in the laboratory, noting the percentage of the spat showing white specks and recording the number of specks per shell. After these data had been depicted on a map of the oyster district, it could easily be demonstrated that shell disease is not evenly distributed. On the contrary, pronounced niduses, showing high figures, could be located in several places. Elsewhere shell disease appeared to be of little or no importance. It is a very characteristic feature that each nidus gradually blends into more healthy areas. No sharp limitations were ever observed. Such maps showing the distribution of shell disease in the spat, have been prepared for several years. There appeared to be a great difference in intensity of attack from year to year, but each nidus, as well as the healthy sites, appeared to occupy a fixed place on the map.

The factor time - after having cleared up the influence of the factor place, I tried to find out the effect of the factor time. Is the oyster liable to infection during all its life? Under what external conditions does the disease attack new victims? What is the fate of oysters once fallen victim to the disease?

Oyster spat appeared to be very sensitive to shell disease. Further, oysters one year old are an easy prey. Thus far, healthy oysters of two years and older appeared to be quite resistant and suffered little, as a rule, even when exposed in the nidus of disease. Placing trays with young oysters in a nidus of disease and examining weekly samples proved to be an excellent measure to follow the events. It soon became evident that shell disease spreads in the summer season, often during a few weeks only. In the remainder of the year the symptoms may aggravate or temporarily come to a standstill, but no new victims are made.

After many years of experiments and observations I was in a position to discover the uniformity in this process. It became clear to me that shell disease only spreads at water temperatures above 19°C. the higher the temperature the more vigorous the attack. Curiously enough a temperature of 19°C. or higher should be maintained for some 10 days before shell disease makes its appearance. If the temperature drops before this period has elapsed, nothing happens. This close correlation between water temperature and attack of shell disease explains the great difference in disease from year to year. In the meantime it offers a possibility to predict a forthcoming attack.

As the appearance of white specks in the shells has been used as an indicator for the spreading of shell disease, we wonder whether or not the first phase of the attack, not to be observed with the naked eye, should be placed much earlier. I carried through extensive transplantation schemes with young oysters, regularly interchanging batches from healthy and diseased places, and found out that the period of incubation is very short. The white specks appear within a few days after the first attack has taken place. Therefore the appearance of white specks is an adequate indicator of the appearance of shell disease. Their number is a measure for its intensity.

What is the fate of oysters fallen victim to the disease, when kept under different external conditions? To investigate this point diseased oysters have been kept under observation during prolonged periods, up to two years. I used oysters of different age groups and placed them under natural conditions in several well selected stations. From these investigations it became evident that nothing happens during the winter season. From October till the end of May the symptoms remained constant. In the warmer season, on the other hand, the disease may aggravate rapidly. White specks increase in numbers, congregate into groups of specks, develop into white clouds in the center of which green, rubber-like material will be laid down in due time. The green spots grow and unite with others, ultimately blockade the edge of the shell, thus making shell growth impossible or shift under the adductor muscle,

which development may prove to be fatal.

As long as shell growth takes place the symptoms of the disease march on. In oysters showing apparently innocent white specks in spring, green spots and warts may appear as early as June, death may follow in July or August. Light cases develop malformations of the shell only. Spat heavily attacked by shell disease may die off quantitatively within a few months. Spat showing a light attack only, survive as a rule, but develop into oysters with badly disfigured hinge parts. If oysters of one year old are severely attacked, there is no hope. They die off quantitatively.

It is no use to transport diseased oysters into a healthy area. As soon as shell growth begins, the symptoms of the disease aggravate, irrespective of where the oysters are grown.

Different methods of oyster culture - it was of the greatest practical importance to find out whether or not spat produced with different methods of oyster culture is equally subject to shell disease. I compared spat on tile-collectors with that on mussel shells and with that attached on the most natural collector, the new shoots of older oysters. I found that the percentage of the spat diseased only depended on the place where I sampled and not on the kind of collector used. Even spat kept well above the bottom on wire covered trays showed the same percentage of diseased as those lying on the bottom nearby. Spat kept within the enclosure of a flood basin and therefore never exposed at low tide, showed the same percentage of victims as spat kept immediately outside that basin and therefore exposed for several hours every day.

This all led to the conclusion that it is the place where the spat is kept during the spreading of the disease in the summer season which determines to what degree it will be liable to shell disease, and not the method of oyster culture practiced.

This conclusion does not involve, however, that the method of oyster culture is of no importance whatever in this connection. Sloping banks along the dikes, the healthiest areas, are best suited for the placing of tile-collectors, but not for the scattering of mussel shells. The oyster farmers, kept informed about the results of our investigations, soon proceeded to place all their tile-collectors in the area indicated by us as free of disease, though this entailed greater expense. The result has been that spat produced with tiles is, to a high degree, free of shell disease and therefore much in demand. Further, the oyster farmers stopped scattering mussel shells on the grounds indicated as the nidus of shell disease. Much spat is still produced, however, on beds at close quarters to the niduses, with the result that its quality is found to be unsatisfactory after warm summers, characterized by a severe attack of shell disease.

The true nature of the disease - though the knowledge acquired on the influence of place, time and method of oyster culture proved to be

of the greatest practical importance and led to instructions to evade an attack of shell disease, we could not be satisfied with abandoning the nidus of shell disease. We wanted to find out the cause of this disease and of its sudden aggravation in the years following 1930.

Generally speaking, there are several different kinds of disease. Some are caused by infection, others by a deficiency in certain constituents in the food. Further, there are diseases caused by extreme deviations from the normal environmental conditions and still other diseases are ascribed to degeneration after prolonged inbreeding.

The characteristics of shell disease, already discussed, allow us to deduce that shell disease in the oyster should be reckoned among the contagious diseases. The short period of its distribution, its regular appearance from year to year, its correlation with water temperature, the occurrence of marked niduses, next to the observation of favourable growth and fattening in non-diseased oysters in the same waters, all point in this direction.

In my pursuit of the cause of this disease I tried to find out whether a parasitic organism could be detected in the diseased mantle epithelium opposite the green spots in the shell. No fungus, bacterium or protozoan could be demonstrated to occur regularly in the diseased tissues. The curious and different patterns of green spots in the individual oysters could hardly be explained by assuming a virus as the cause of the disease. Efforts to isolate an infectious organism from the diseased tissues by the approved laboratory techniques failed to yield positive results and so did my efforts to infect healthy oysters by injecting preparations of diseased mantle tissue.

Though the diseased tissue opposite the green spots and warts can easily be recognized under the microscope and often even with the naked eye, I failed to recognize any aberrant feature in the mantle epithelium opposite the white specks, which always precede the appearance of green spots in diseased oysters. After many vain attempts I decided to follow other paths in investigating this particular phase in shell disease. If the white specks in the shell should be ascribed to slight aberrations in the shell secreting mantle tissue, though I failed to detect such aberrations in my serial sections, they should be reproduced in the same characteristic patterns in case that particular piece of the shell had been taken away. I carried through this experiment and was surprised to find that the shell layers, which had been secreted to replace the pieces of shell taken away from the edge, were always free of white specks and other symptoms of disease. Then I started another experiment in which a piece of shell, bearing white specks, was carefully implanted in the shell edge of a healthy oyster. After new growth had been put on, the layers of shell deposited on the implantate appeared to suffer from shell disease, while the remainder of the shell was as healthy as before.

These experiments proved that the disease, in its early development, had its seat in the shell itself and that aberration of the living mantle tissue is a feature of a later phase.

Further, I found out that shells of oysters living in a nidus of shell disease are not attacked throughout their entire surface. Only recent new growth and other parts of the shell, which happen to be very thin, such as the shells of young spat, can be invaded by the white specks. Thickerparts of the shell cannot be attacked. Moreover, parts of the shell which are not freely accessible from the outside like the undermost shells of spat settled on tile- collectors, are always free of shell disease, even when the shells are very thin.

This all eventually led to the conclusion that the shell is attacked from the outside. The infective organism must have the power to perforate thin parts of the shell before it can start exercising its fatal influence on the living tissues. This influence first causes only minor aberrations in shell secretion, resulting in tiny white specks on the inside of the shell. Later its action brings about irreversible changes in the living mantle tissue, ultimately resulting in serious deformations of the shell or even in death.

It seems incredible that a bacterium or a virus is able to perforate oyster shells, which only a fungus can do. Using the technique of the geologist, I produced thin slides of oyster shells. Investigating early phases of shell disease, I found that every white speck has a narrow hole in its centre, in which hole a fungus thread can be found making its way towards the shell's interior. After its arrival there it branches abundantly and obviously starts irritating the living tissues. This first leads to minor aberrations, like the white specks and white clouds, but ultimately to serious defects and even death.

The entire process resembles strikingly the events during the formation of plant galls. There, too, the secretion of a tiny organism, an egg, a maggot or a fungus, leads to aberrations in the normal development of the growing plant tissues, and ultimately leads to complicated deformations, constructed of the plant's normal cells, but produced in abnormal places and in abnormal quantities.

Characteristic features of a nidus of shell disease - the next problem was to find out why the fungus is so abundant in the nidus of disease and not elsewhere. The gradual transition from a nidus of disease to a healthy area and the fact that oysters kept on trays suffered as much as those lying on the bottom, led me to the conclusion that shell disease is water-borne.

I assume that large numbers of spores of the fungus responsible for shell disease are produced in each nidus, attacking all the oysters there and spreading gradually to more healthy areas carried by the tidal currents. The further away from the nidus, the more the spores become diluted, hence a smaller and smaller number of white specks in the oysters and a larger and larger percentage of oysters entirely free from specks as we enter a healthy area.

A closer investigation of the nidus of disease led us to the remarkable conclusion that the number of diseased oysters, which could be considered to represent the source of each new infection, often is very limited. Even on several of the most dangerous spots diseased oysters, more than one year old, were totally absent. The only constant feature of each nidus of shell disease appeared to be a high percentage of old shells in the superficial bottom layers. These old shells, most of them cockle shells (Cardium edule), were brought there in earlier years as collecters but, owing to fouling, no longer served for this purpose. Maps depicting the quantity of shells in superficial bottom layers resemble so closely the maps depecting the distribution of shell disease that they are virtually identical.

The colour of the old shells is green due to perforating algae. Next to algae the old shells appeared to lodge an abundance of fungus threads. The shells being free of organic matter themselves, the fungus probably gets its food from the perforating algae.

Is it too bold to assume that the spores infecting the oysters are produced by the fungus living in the old shells and reproducing in the warmest part of the summer season? I was in a position to demonstrate that this is really what happens! In a season characterized by a very intense spatfall some spat could be found on the old fouled green shells. This spat was invariably in a very bad state. It proved to suffer from an immediate attack of the fungus living inside the old shells. Apparently it is very easy for the fungus to perforate the thin undermost shell of the newly settled spat. This undermost shell, which cannot be reached by the spores, is always free of disease in spat on tiles and on newly scattered shells. This treacherous attack in the rear even takes place at water temperatures below 19°C. during which no spores are produced, so that spat on tiles and newly scattered shells remain healthy.

The immense jigsaw-puzzle was now complete. The fungus living in the old green shells produces spores on a very great scale in the warmest part of the summer season. These spores are carried about by the water currents. The spores are able to perforate the young growth of oyster shells and to start a parasitic life there, with all the disagreeable consequences known to us as shell disease. Other spores find their way to old shells and start a more innocent life in co-operation with perforating algae.

This makes clear why, in our experiments, a limited number of diseased shells and limited quantities of old shells failed to infect healthy young oysters kept on the same tray in a healthy area. Obviously, the dilution of the spores by the water currents is far too great under such conditions. Further, it is now easily understood why it proved to be useless to clean a limited space in a nidus of shell disease from old shells, for spores are amply supplied from the surrounding grounds.

The cause of the explosion of disease about 1930 - an explanation could be found for the remarkable fact that shell disease spread so rapidly and fatally in the years following 1930. Our first Government Fisheries Biologist, Dr. Hoek, described shell disease in 1900 and stated that it occurred only in a limited percentage of the oysters at that time. Between 1920 and 1930 enormous quantities of cockle shells had been scattered as collectors in a foolish effort to raise the production of young oysters. Instead of about 5,000 $M^3$ shells, 40,000 to 50,000 $M^3$ were used annually. This gave the fungus its chance to proliferate enormously. Hence the number of spores produced annually soon rose to an alarming and fatal level, and shell disease, once obscure, exploded.

I believe that shell disease occurs on many of the European oyster beds. Most probably it is identical with the French Maladie-du-pied. I have seen its victims in Brittany and once I came across a batch of oysters from a natural oyster bed in Brittany, which were diseased in a very high percentage and in a very bad state. It turned out that they came from a bed rich in old shells, which were kept there as a method of conservation.

Methods of control - our profound knowledge of shell disease, gathered in the course of many years, eventually led to appropriate methods of control.

Our earliest advice was to evade the niduses of disease and to concentrate spat production in the area indicated as healthy. Ultimately we could encourage the wholesale cleaning of old abandoned beds to get rid of the old green shells, which produce the fatal spores every summer. I cannot deny that a lot of red tape had to be unwound before the united oyster farmers started to clean the unproductive abandoned oyster beds at their own expense. We try now to keep the oyster beds in perfect condition and to avoid any accumulation of shells by regimenting the use of mussel shells as collectors. It is prohibited now to use the resistant cockle shells as cultch.

The most spectacular method of control, giving almost immediate success and recently applied on a very large scale by our oyster farmers, is a disinfection of the diseased oysters. After extensive experiments it appeared to be possible to kill the fungus within the oyster shell by bathing the oyster for an hour in a toxic solution, using an organic salt of mercury. The oyster closes its shells tightly in this solution and is not injured at all, but the fungus is killed within the shell because the toxic product enters through the hole the fungus drilled in entering the shell. This method can only be applied as long as the disease is in its early developmental stage. As soon as green rubber-like spots make their appearance in the shell, indicating that the living tissues have been changed irreversibly, chemical control is no longer possible. Disinfection has been practiced on a very large scale and with great success after the heavy attack of shell disease in the warm summer of 1947.

Shell disease, once a serious menace to the Dutch oyster culture, threatening to destroy this important industry, had its mysteries revealed bit by bit in the course of our investigations. Difficulties arose from the necessity of carrying out all the crucial experiments in the field and obtaining the results at the end of each summer season. A new set of experiments could not be started before the onset of growth in the next spring. It goes without saying that war difficulties during the German occupation hampered our work in no little measure. We were short of adequately equipped boats and fuel amenable to German restrictions in the coastal area, and often exposed to the dangers of war.

We know now how to combat this disease which caused such heavy losses and reduced so much the quality of our oysters. Oysters recently attacked are saved by applying disinfection. The wholesale cleaning of the niduses of disease now in operation will, no doubt, relegate this disease to the modest place it formerly occupied.